Testing Endoscope performance

Appl New Ref.

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United States Patent [19]

Rosow et al.

[11] **Patent Number: 5,953,112**

[45] **Date of Patent: Sep. 14, 1999**

[54] **METHOD AND APPARATUS FOR EVALUATING THE PERFORMANCE CHARACTERISTICS OF ENDOSCOPES**

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[73] Assignee: **Hartford Hospital**, Harford, Conn.

[21] Appl. No.: **08/821,112**

[22] Filed: **Mar. 20, 1997**

[51] **Int. Cl.**[6] **G01N 21/00**

[52] **U.S. Cl.** **356/73.1**; 356/388; 356/121

[58] **Field of Search** 356/73.1, 388, 356/121

[56] **References Cited**

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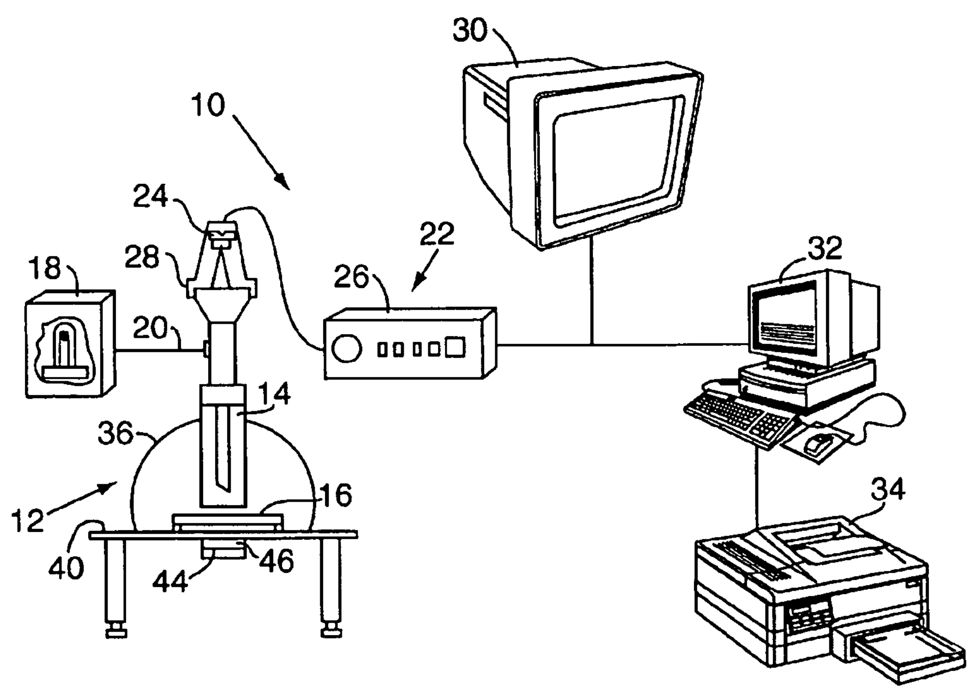
Primary Examiner—Frank G. Font
Assistant Examiner—Reginald A. Ratliff
Attorney, Agent, or Firm—McCormick, Paulding & Huber LLP

[57] **ABSTRACT**

In a method and apparatus for evaluating the performance characteristics of fiber-optic endoscopes, a beam of light defining a predetermined intensity pattern is transmitted through the endoscope from a tip end through an eyepiece end of the endoscope. The intensity pattern of the beam defines either a uniform intensity, or an intensity which varies sinusoidally in a predetermined direction across the beam. The following tests are performed in order to evaluate both the optical fibers and the lens system of the endoscope, and the intensity pattern is selected in accordance with the requirements of the respective test: (i) a light loss test, (ii) a reflective symmetry test, (iii) a lighted fibers test, (iv) a geometric distortion test, and (v) a MTF test. A video system generates signals indicative of the optical intensity of the beam after transmission through the endoscope at each of a plurality of predetermined locations within the beam. The video signals are in turn evaluated in accordance with the selected tests in order to provide graphical and numerical indicia of the optical performance characteristics of the endoscope.

43 Claims, 20 Drawing Sheets



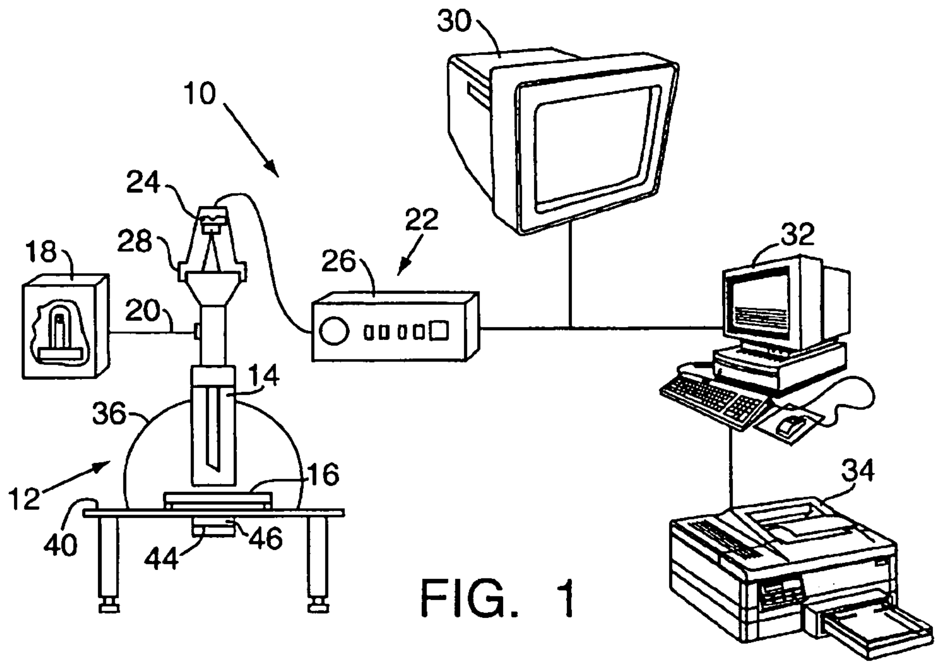


FIG. 1

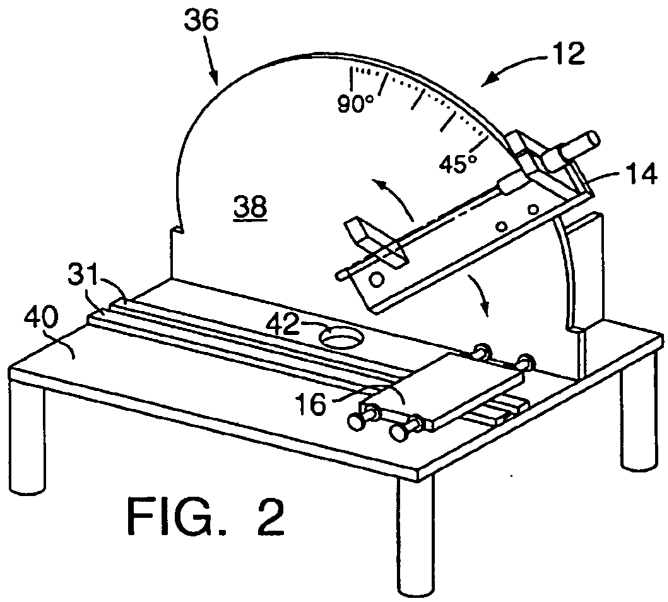


FIG. 2

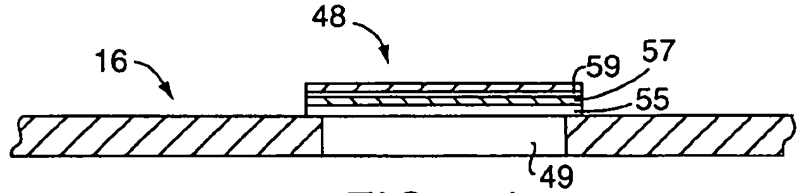
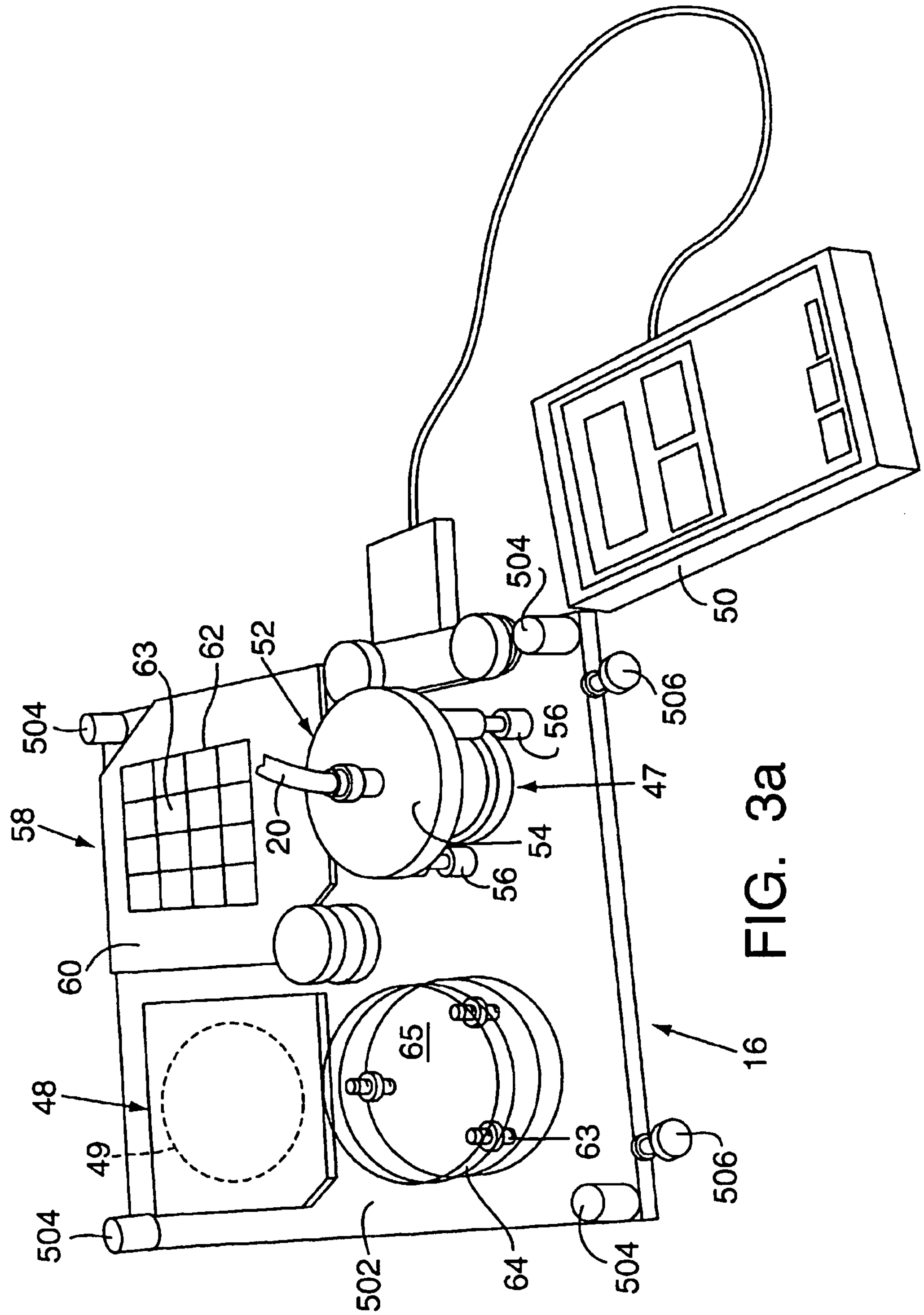


FIG. 3b



50
504
506
56
47
54
56
52
62
63
504
58
20
60
65
48
49
63
506
504
502
64
504
16

FIG. 3a

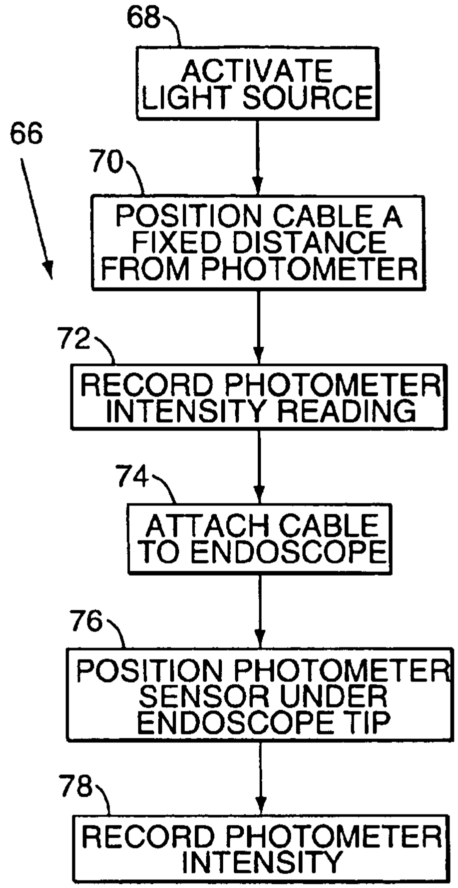


FIG. 4

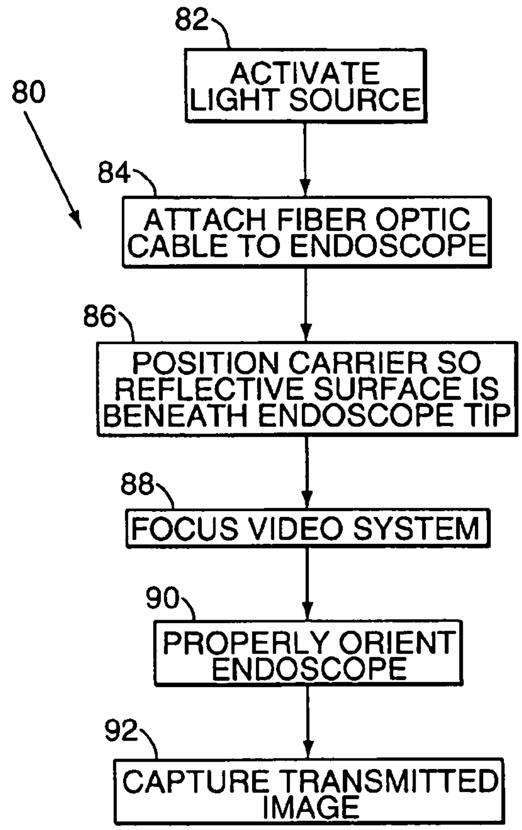


FIG. 5

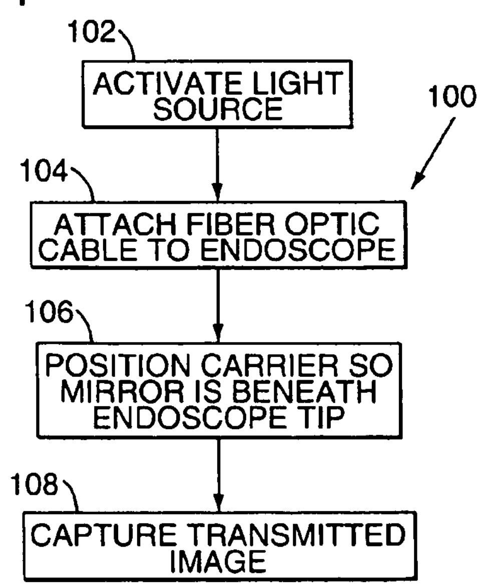


FIG. 6

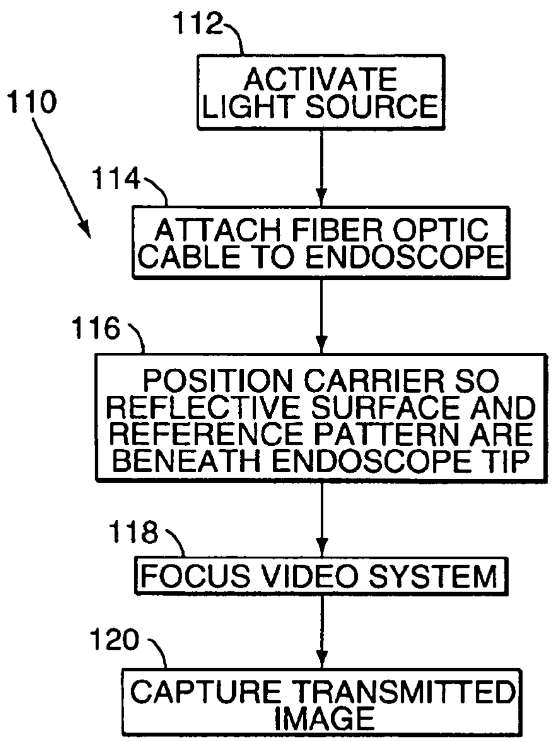

110
112
ACTIVATE LIGHT SOURCE
114
ATTACH FIBER OPTIC CABLE TO ENDOSCOPE
116
POSITION CARRIER SO REFLECTIVE SURFACE AND REFERENCE PATTERN ARE BENEATH ENDOSCOPE TIP
118
FOCUS VIDEO SYSTEM
120
CAPTURE TRANSMITTED IMAGE

FIG. 7

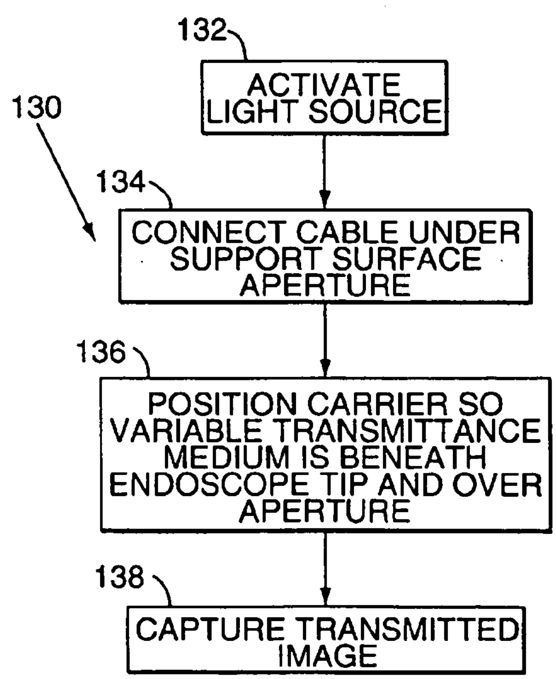

130
132
ACTIVATE LIGHT SOURCE
134
CONNECT CABLE UNDER SUPPORT SURFACE APERTURE
136
POSITION CARRIER SO VARIABLE TRANSMITTANCE MEDIUM IS BENEATH ENDOSCOPE TIP AND OVER APERTURE
138
CAPTURE TRANSMITTED IMAGE

FIG. 8

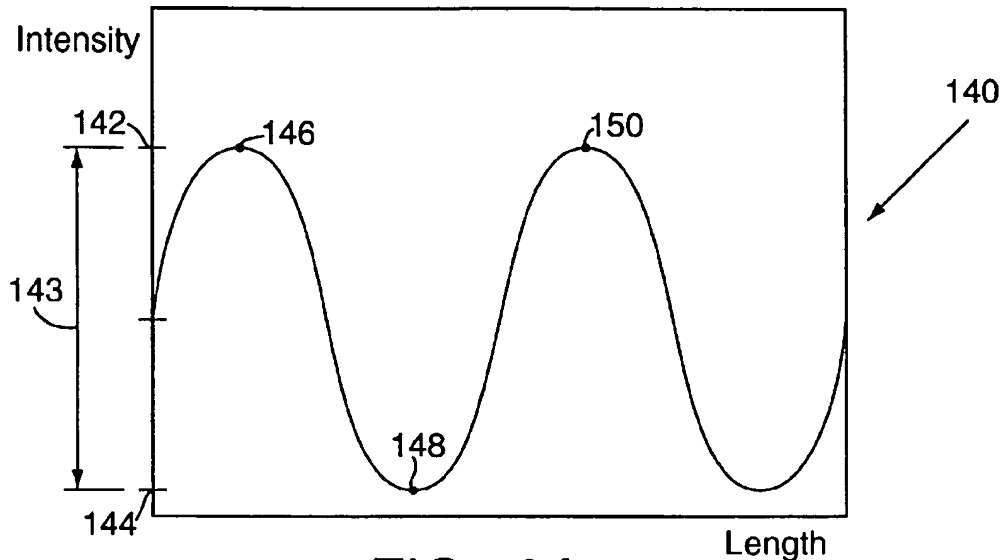

Intensity
142
146
150
140
143
148
144
Length

FIG. 9A

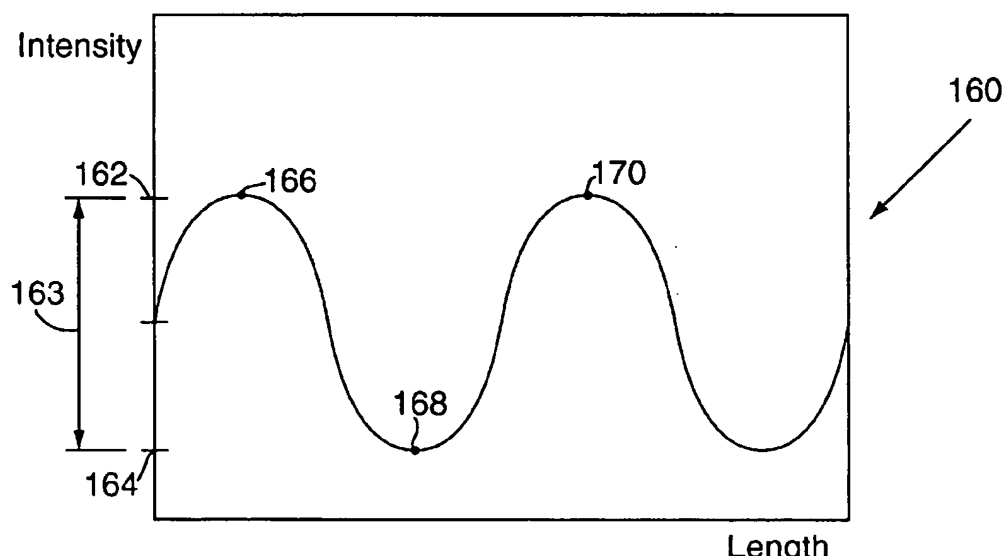

Intensity
162
166
170
160
163
168
164
Length

FIG. 9B

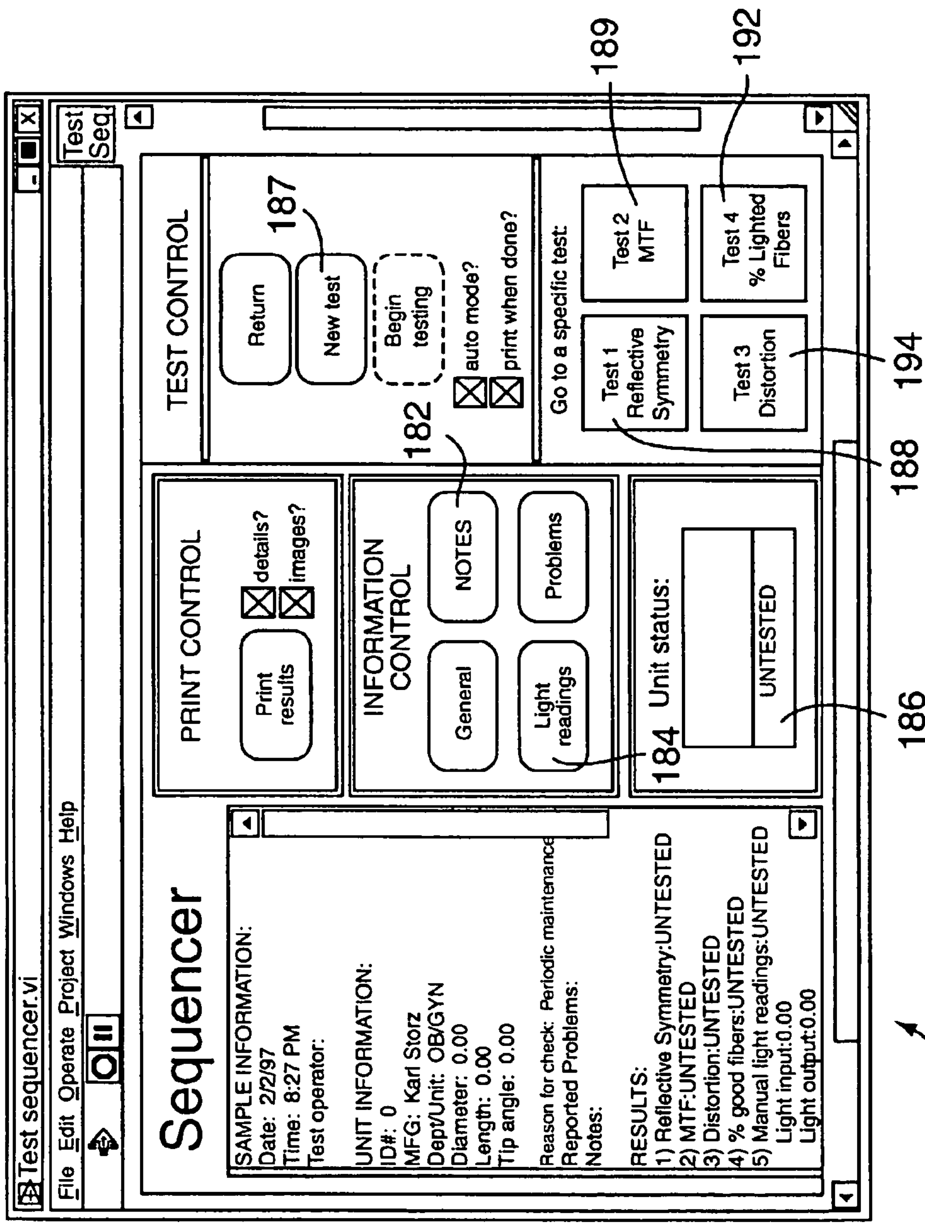

Test sequencer.vi
File Edit Operate Project Windows Help
Sequencer
SAMPLE INFORMATION:
Date: 2/2/97
Time: 8:27 PM
Test operator:
UNIT INFORMATION:
ID#: 0
MFG: Karl Storz
Dept/Unit: OB/GYN
Diameter: 0.00
Length: 0.00
Tip angle: 0.00
Reason for check: Periodic maintenance
Reported Problems:
Notes:
RESULTS:
1) Reflective Symmetry:UNTESTED
2) MTF:UNTESTED
3) Distortion:UNTESTED
4) % good fibers:UNTESTED
5) Manual light readings:UNTESTED
Light input:0.00
Light output:0.00
PRINT CONTROL
Print results
details?
images?
INFORMATION CONTROL
General
NOTES
Light readings
Problems
Unit status:
UNTESTED
TEST CONTROL
Return
New test
Begin testing
auto mode?
print when done?
Go to a specific test:
Test 1 Reflective Symmetry
Test 2 MTF
Test 3 Distortion
Test 4 % Lighted Fibers
Test Seq.
180
182
184
186
187
188
189
192
194

FIG. 10

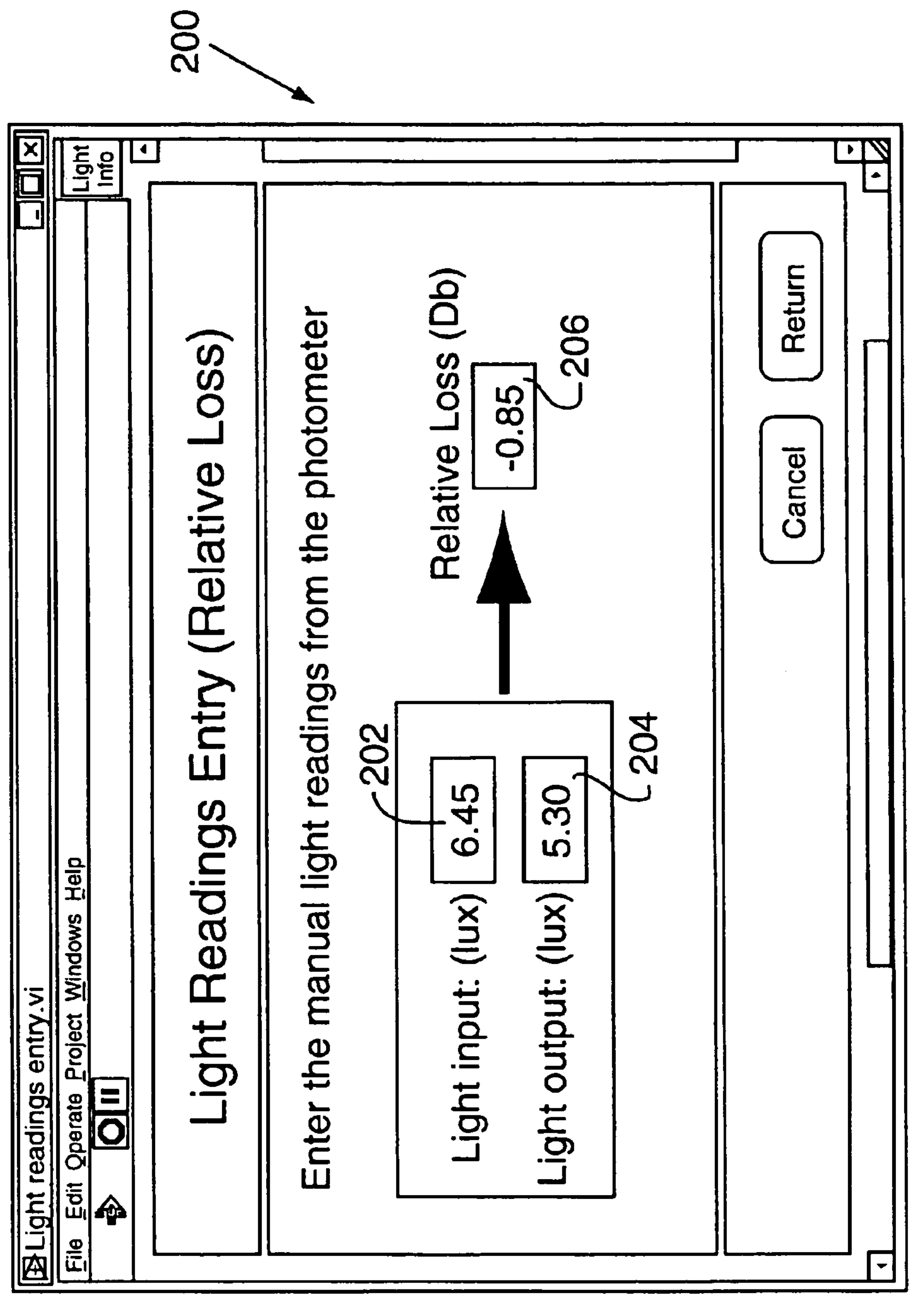

200
Light readings entry.vi
File Edit Operate Project Windows Help
Light Info
Light Readings Entry (Relative Loss)
Enter the manual light readings from the photometer
Light input: (lux)
6.45
202
Light output: (lux)
5.30
204
Relative Loss (Db)
-0.85
206
Cancel
Return

FIG. 11

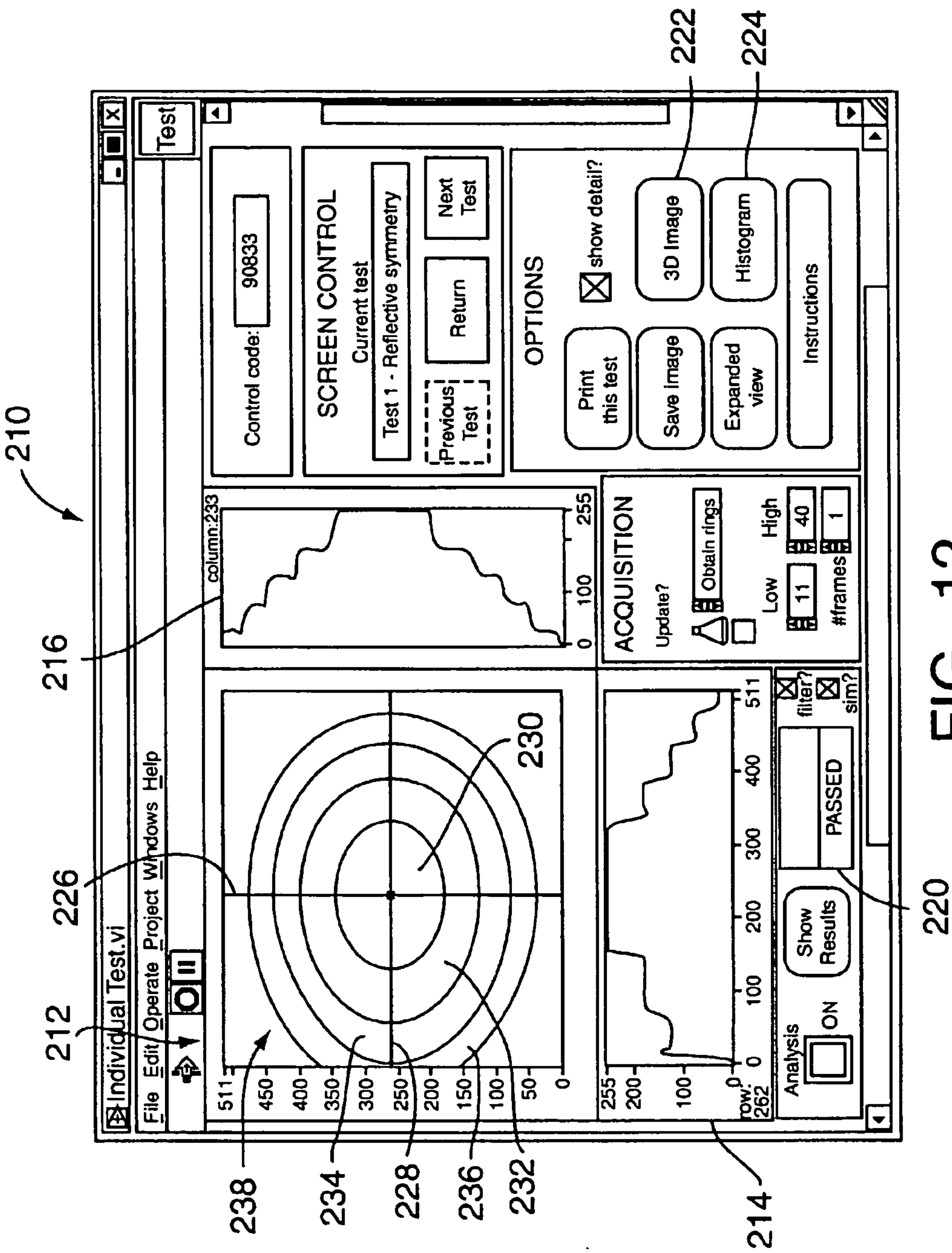

210
212
214
216
220
222
224
226
228
230
232
234
236
238
Individual Test.vi
File Edit Operate Project Windows Help
Test
Control code: 90833
SCREEN CONTROL
Current test
Test 1 - Reflective symmetry
Previous Test
Return
Next Test
OPTIONS
show detail?
Print this test
Save Image
Expanded view
Instructions
3D Image
Histogram
ACQUISITION
Update?
Obtain rings
Low 11
High 40
#frames 1
column:233
0 100 255
row: 262
Analysis ON
Show Results
PASSED
filter?
sim?
511 450 400 350 300 250 200 150 100 50 0
255 200 100 0
0 100 200 300 400 511

FIG. 12

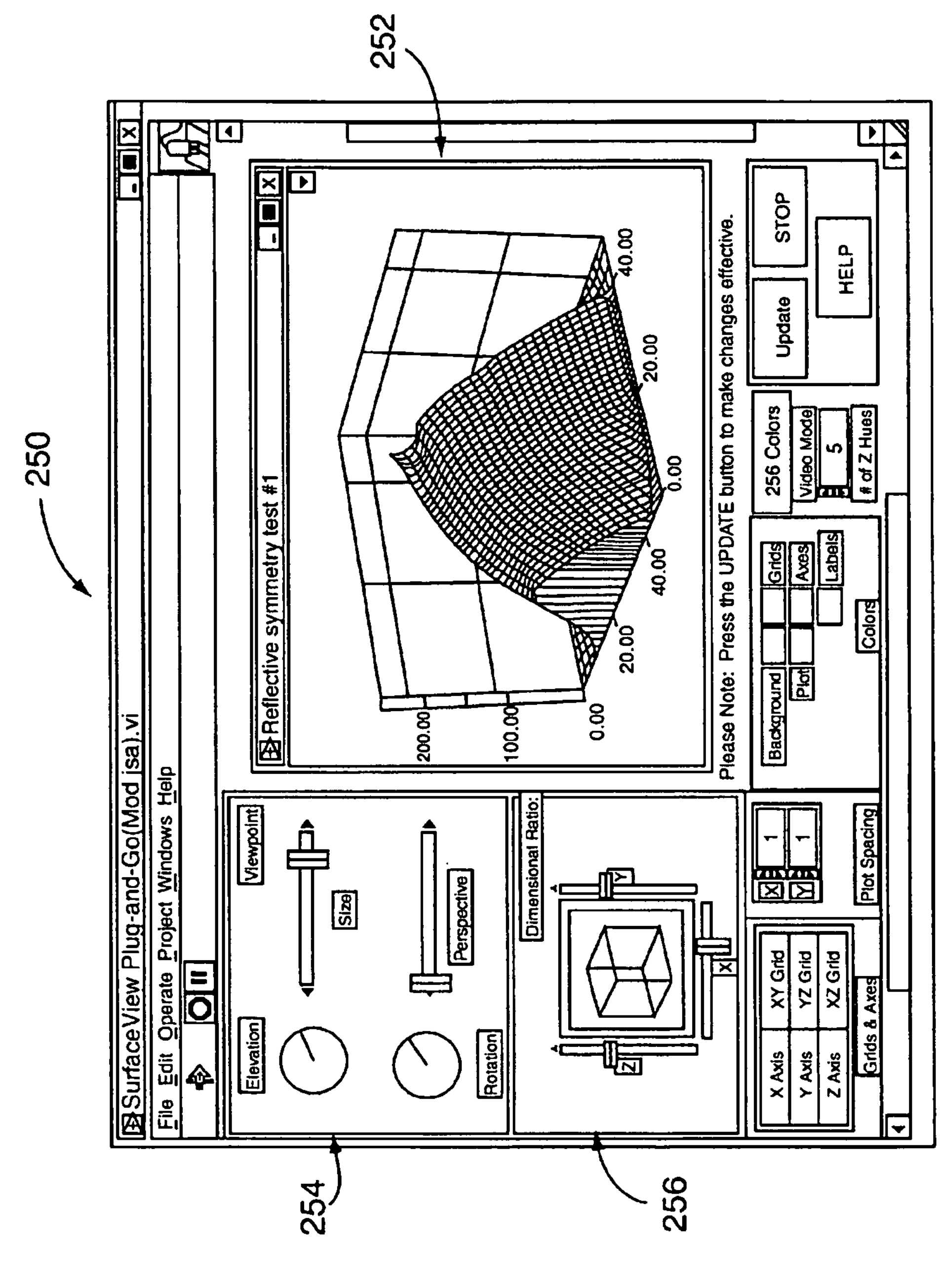

250
252
254
256
SurfaceView Plug-and-Go(Mod isa).vi
File Edit Operate Project Windows Help
Reflective symmetry test #1
200.00
100.00
0.00
20.00
40.00
0.00
20.00
40.00
Please Note: Press the UPDATE button to make changes effective.
Elevation
Viewpoint
Size
Perspective
Rotation
Dimensional Ratio:
X
Y
Z
Background
Plot
Grids
Axes
Labels
Colors
256 Colors
Video Mode
5
# of Z Hues
Update
STOP
HELP
1
1
Plot Spacing
X Axis
Y Axis
Z Axis
XY Grid
YZ Grid
XZ Grid
Grids & Axes

FIG. 13

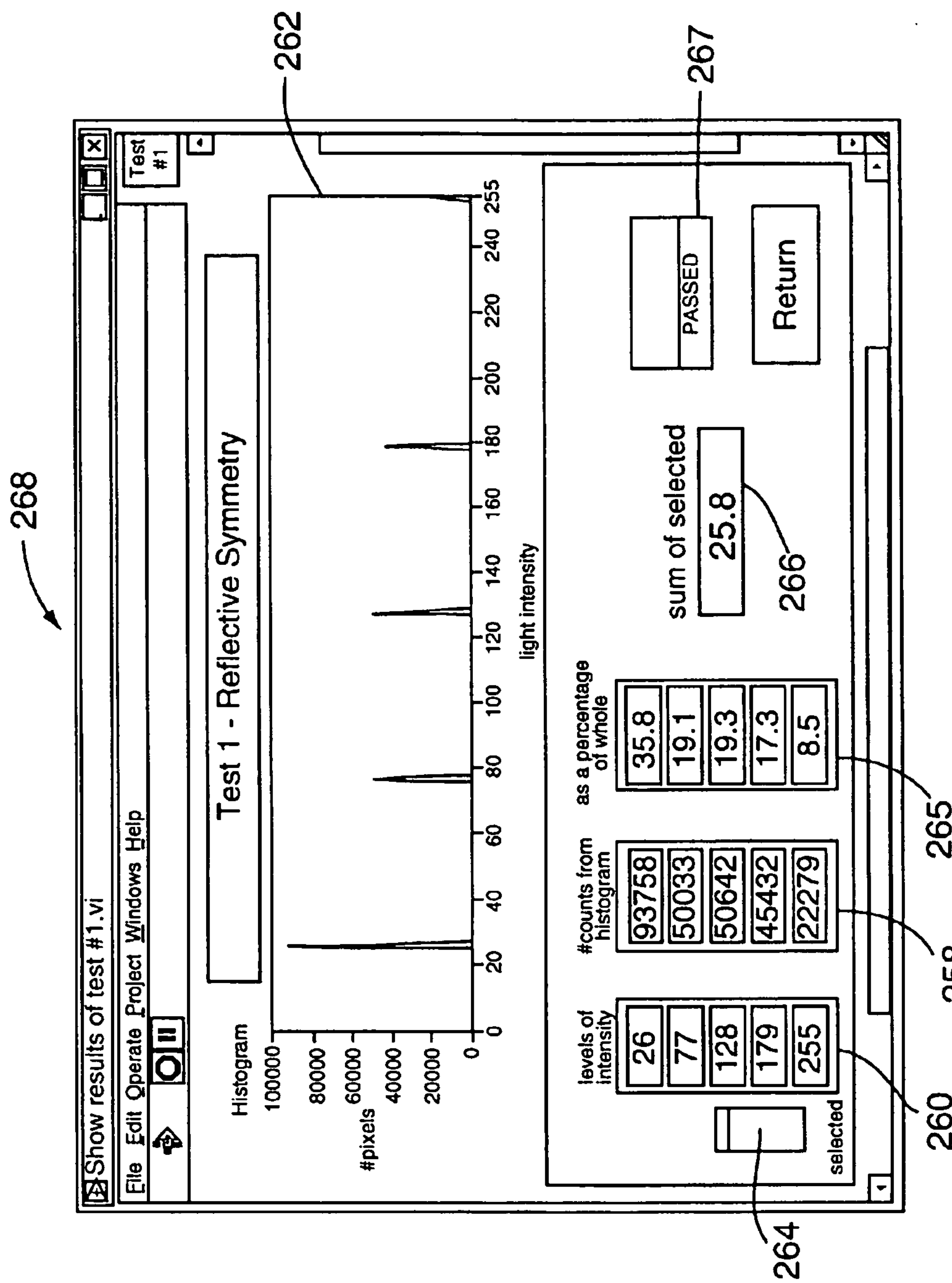

268
Show results of test #1.vi
File Edit Operate Project Windows Help
Test #1
Test 1 - Reflective Symmetry
Histogram
#pixels
100000
80000
60000
40000
20000
0
0 20 40 60 80 100 120 140 160 180 200 220 240 255
light intensity
262
selected
levels of intensity
26
77
128
179
255
#counts from histogram
93758
50033
50642
45432
22279
as a percentage of whole
35.8
19.1
19.3
17.3
8.5
sum of selected
25.8
PASSED
Return
264
260
258
265
266
267

FIG. 14

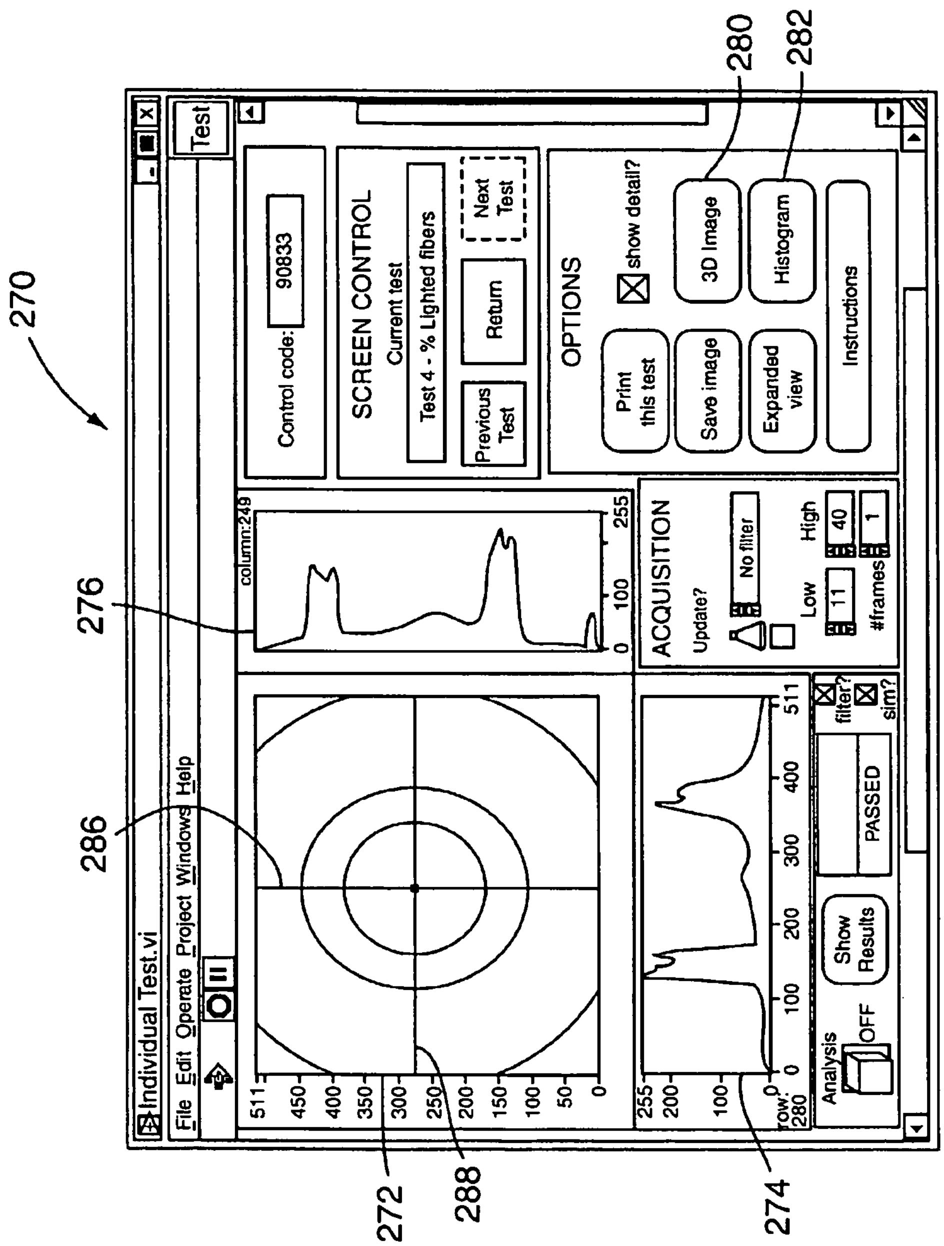

270
276
286
280
282
272
288
274
Individual Test.vi
File Edit Operate Project Windows Help
Test
Control code:
90833
SCREEN CONTROL
Current test
Test 4 - % Lighted fibers
Previous Test
Return
Next Test
OPTIONS
show detail?
Print this test
Save image
Expanded view
Instructions
3D Image
Histogram
column:249
ACQUISITION
Update?
No filter
Low
High
11
40
#frames
1
Analysis
OFF
Show Results
PASSED
filter?
sim?
row: 280

FIG. 15a

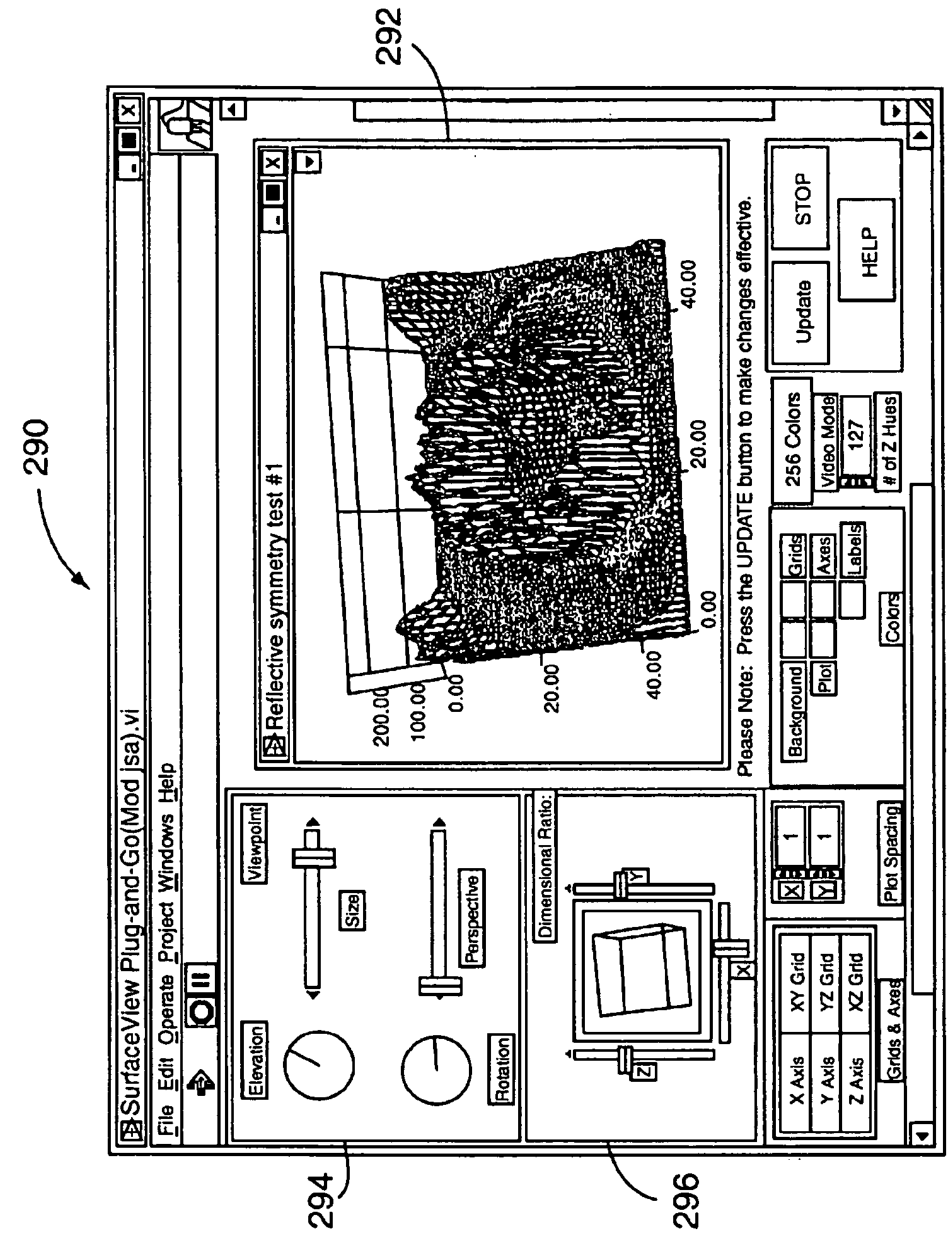
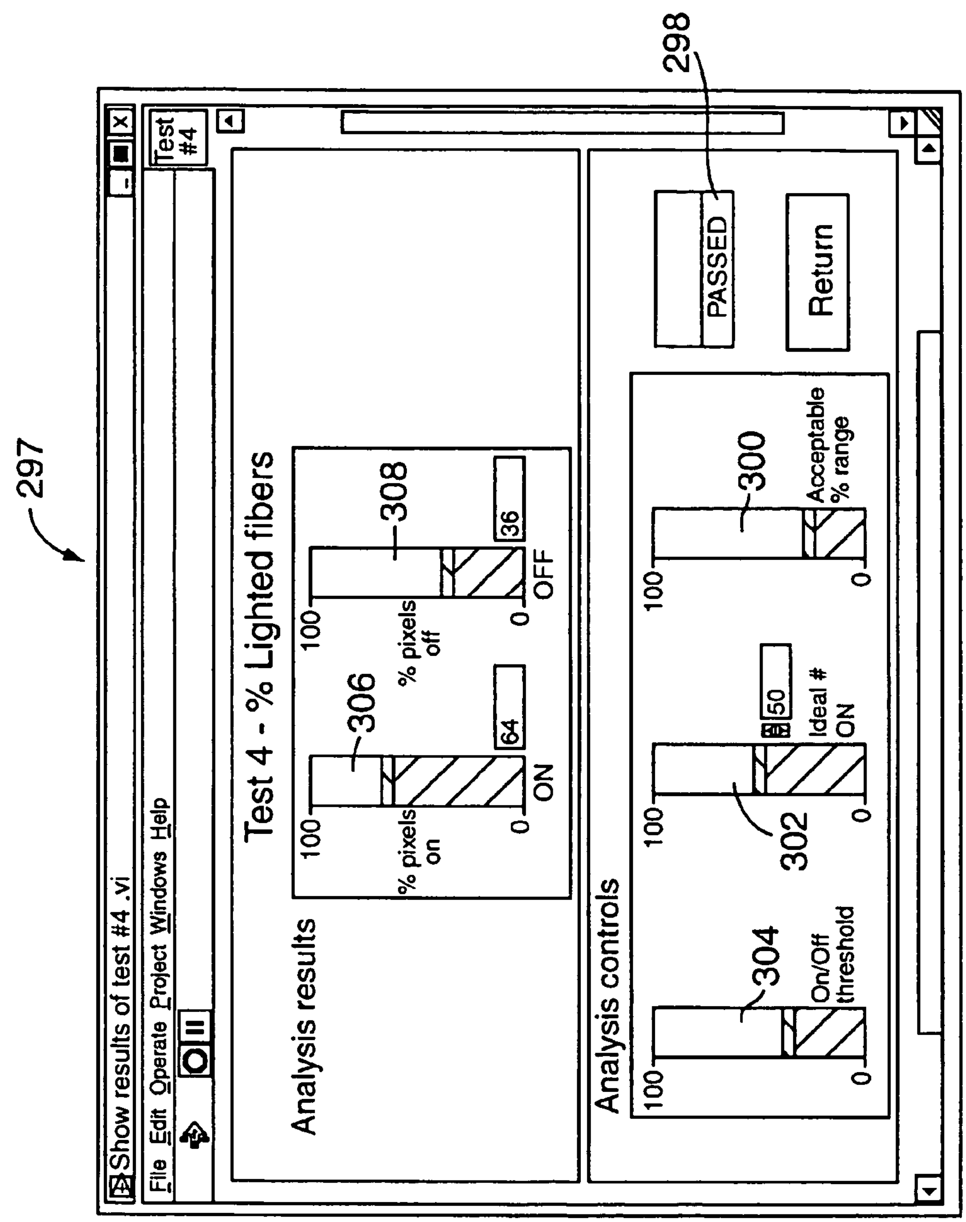

290
292
294
296
SurfaceView Plug-and-Go(Mod jsa).vi
File Edit Operate Project Windows Help
Reflective symmetry test #1
Elevation
Viewpoint
Size
Perspective
Rotation
Dimensional Ratio:
Please Note: Press the UPDATE button to make changes effective.
Background
Plot
Grids
Axes
Labels
Colors
256 Colors
Video Mode
127
# of Z Hues
Update
STOP
HELP
X Axis
Y Axis
Z Axis
XY Grid
YZ Grid
XZ Grid
Grids & Axes
Plot Spacing

FIG. 15b



297
Show results of test #4 .vi
File Edit Operate Project Windows Help
Test #4
Analysis results
Test 4 - % Lighted fibers
100
0
% pixels on
ON
64
306
% pixels off
OFF
36
308
Analysis controls
On/Off threshold
304
302
Ideal # ON
50
300
Acceptable % range
PASSED
298
Return

FIG. 16

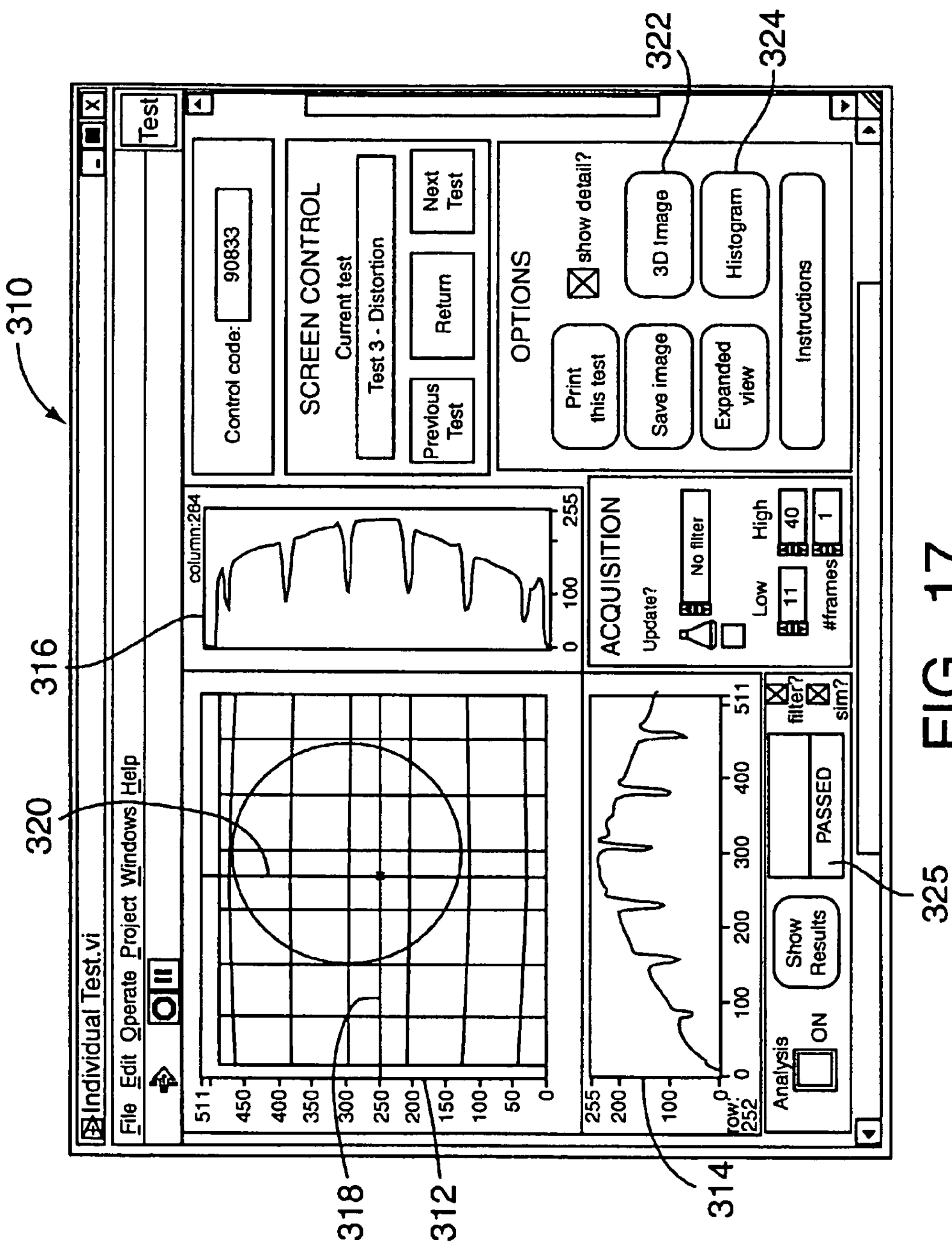

310
312
314
316
318
320
322
324
325
Individual Test.vi
File Edit Operate Project Windows Help
Test
Control code: 90833
SCREEN CONTROL
Current test
Test 3 - Distortion
Previous Test
Return
Next Test
OPTIONS
show detail?
Print this test
Save image
Expanded view
Instructions
3D Image
Histogram
column:284
ACQUISITION
Update?
No filter
Low
High
11
40
#frames
1
filter?
sim?
PASSED
Show Results
Analysis
ON
row: 252

FIG. 17

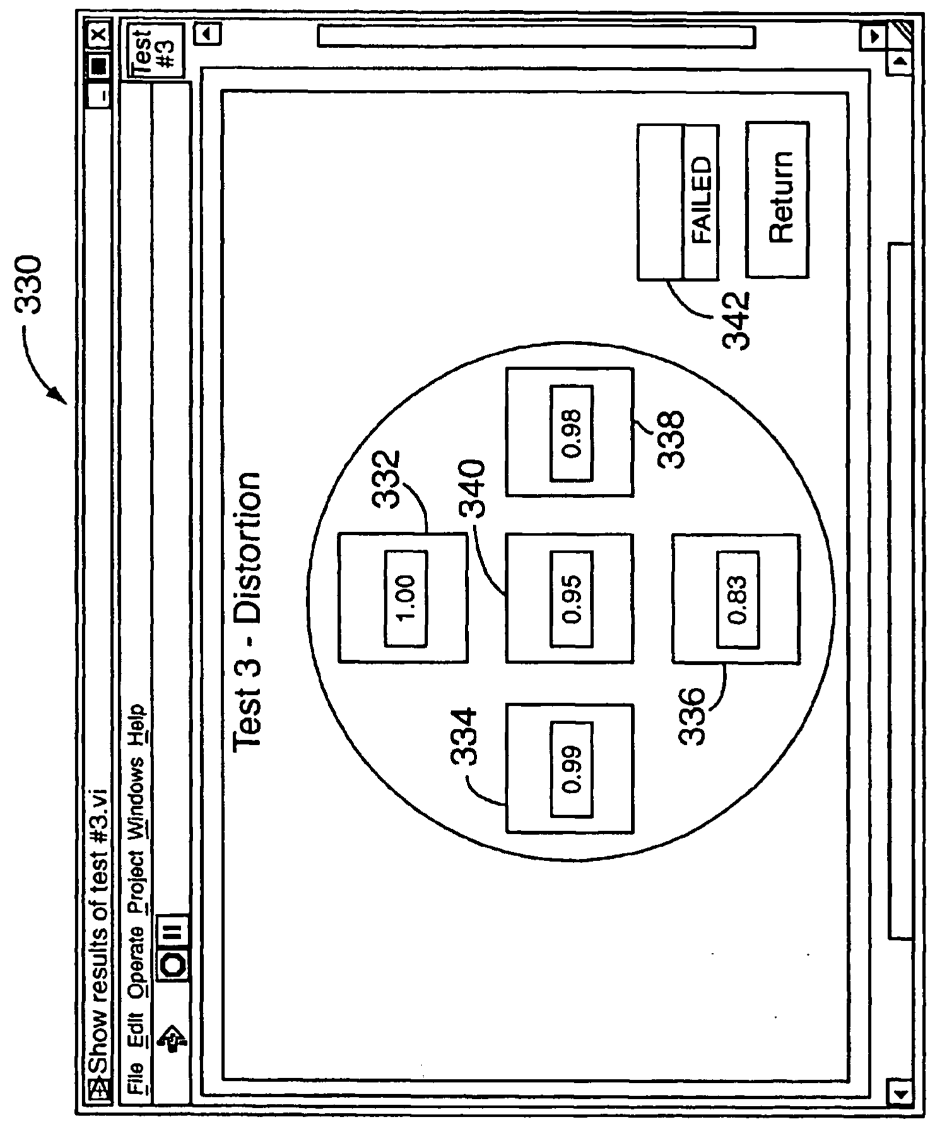

330
Show results of test #3.vi
File Edit Operate Project Windows Help
Test #3
Test 3 - Distortion
1.00
0.95
0.83
0.99
0.98
332
334
336
338
340
342
FAILED
Return

FIG. 18

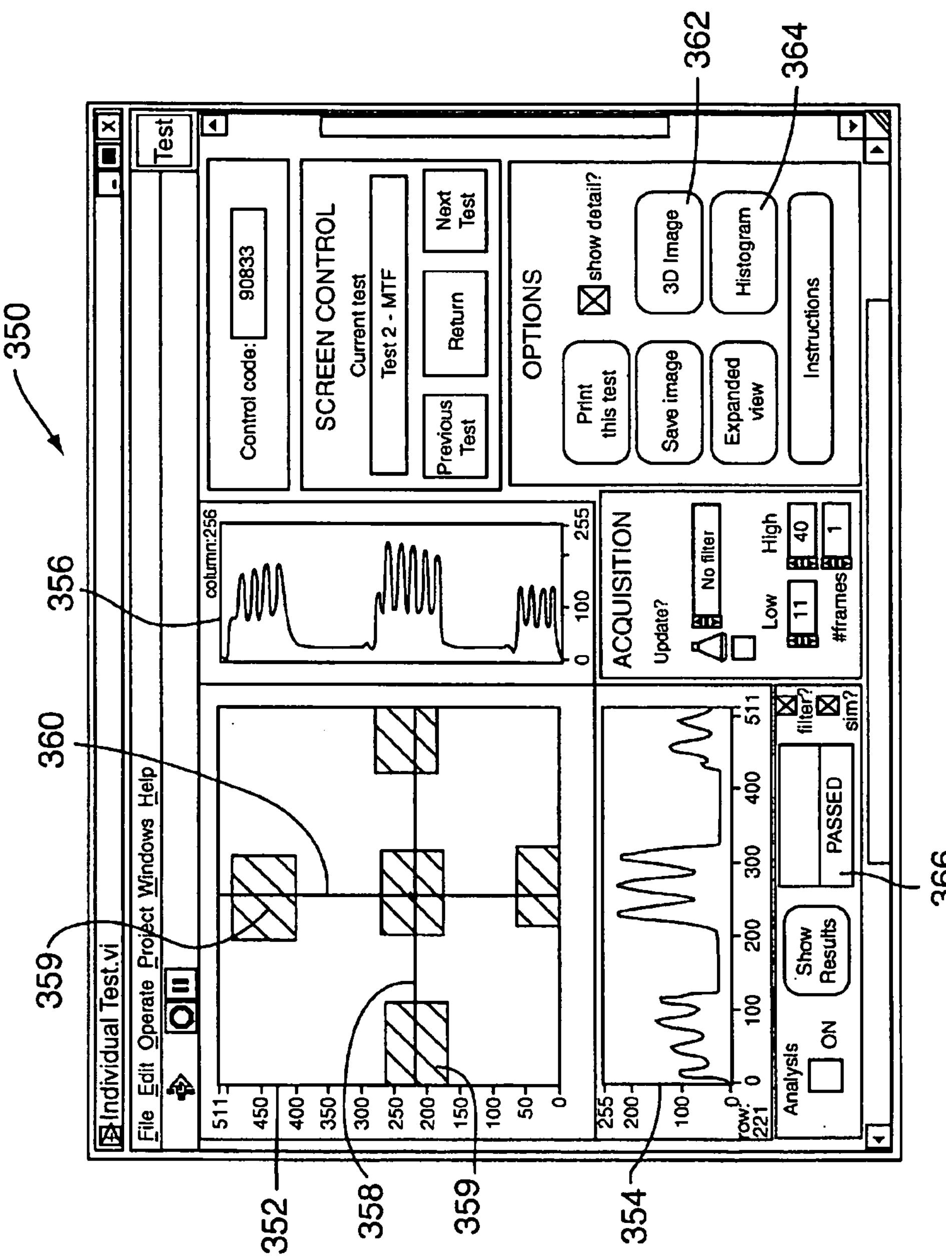

350
Individual Test.vi
File Edit Operate Project Windows Help
Test
Control code: 90833
SCREEN CONTROL
Current test
Test 2 - MTF
Previous Test
Return
Next Test
OPTIONS
show detail?
Print this test
Save image
Expanded view
Instructions
3D Image
Histogram
column:256
ACQUISITION
Update?
No filter
Low
High
#frames
Analysis
ON
Show Results
PASSED
filter?
sim?
row: 221
352
354
356
358
359
360
362
364
366

FIG. 19

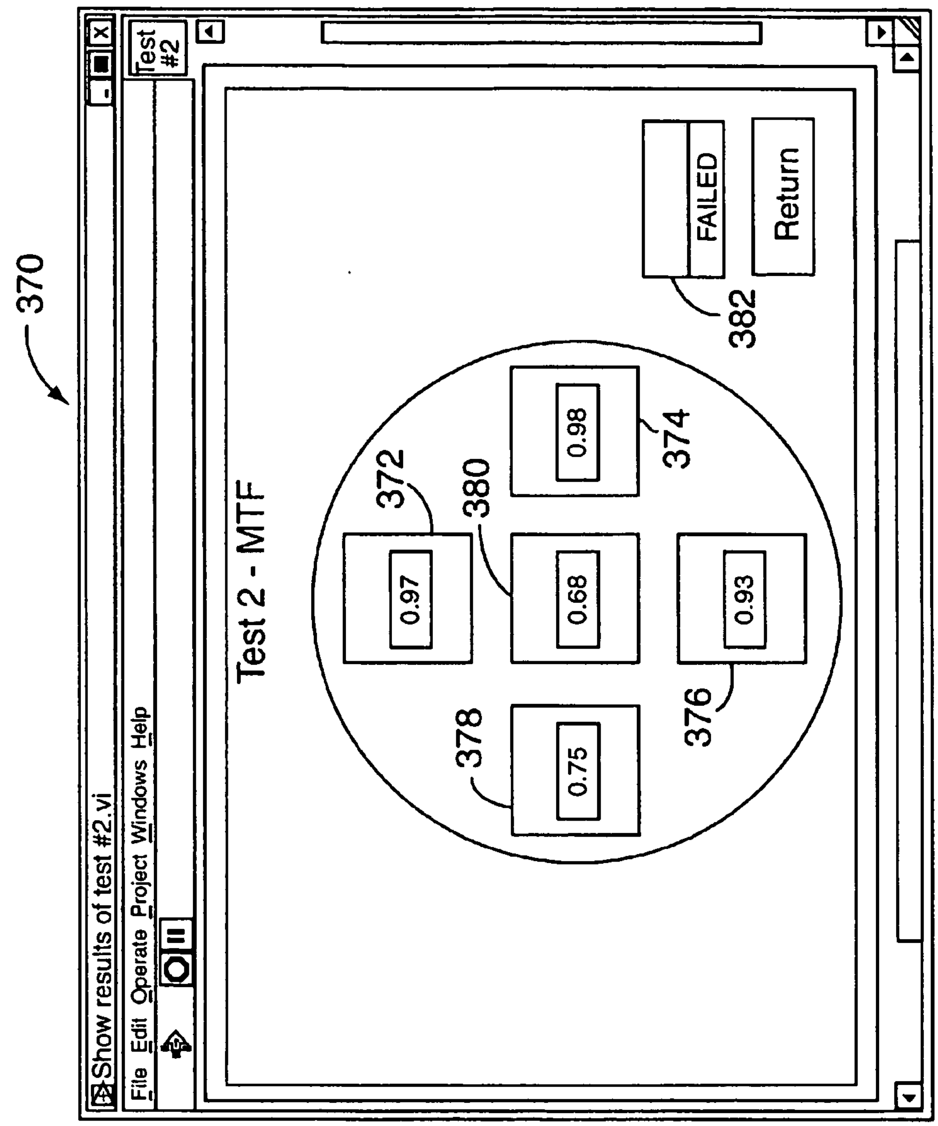
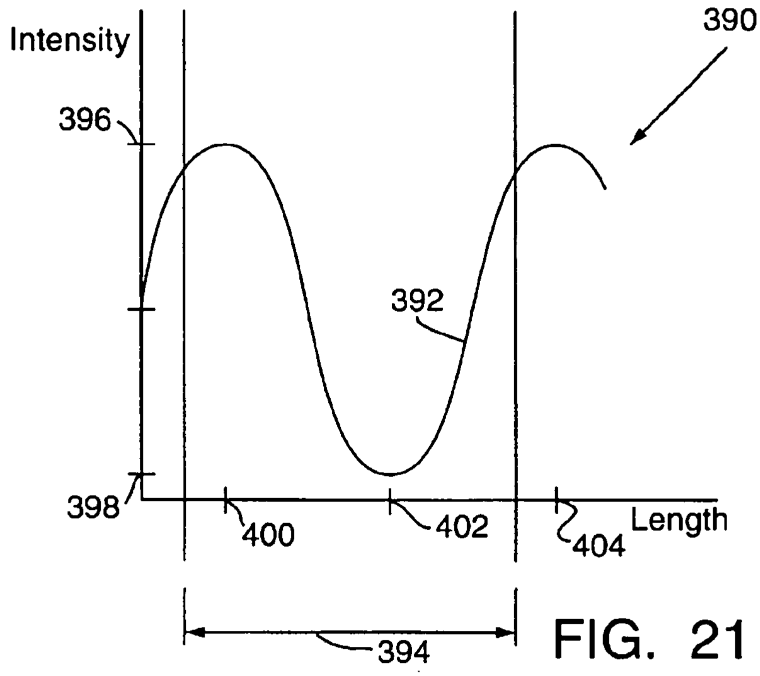
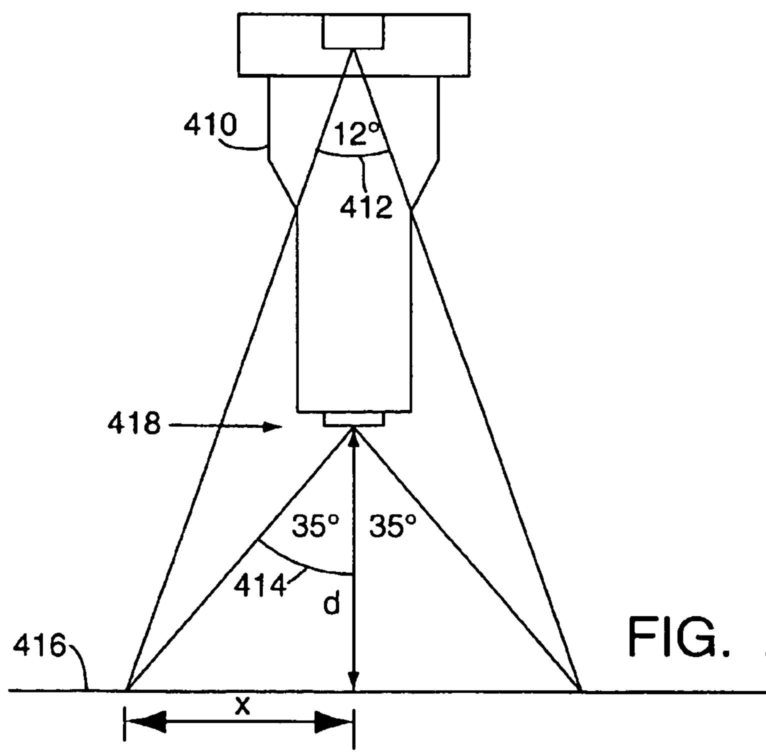

370
Show results of test #2.vi
File Edit Operate Project Windows Help
Test #2
Test 2 - MTF
372
380
374
0.97
0.68
0.98
0.93
0.75
378
376
FAILED
382
Return

FIG. 20



Intensity
390
396
392
398
400
402
404
Length
394

FIG. 21



410
12°
412
418
35°
35°
414
d
416
x

FIG. 22

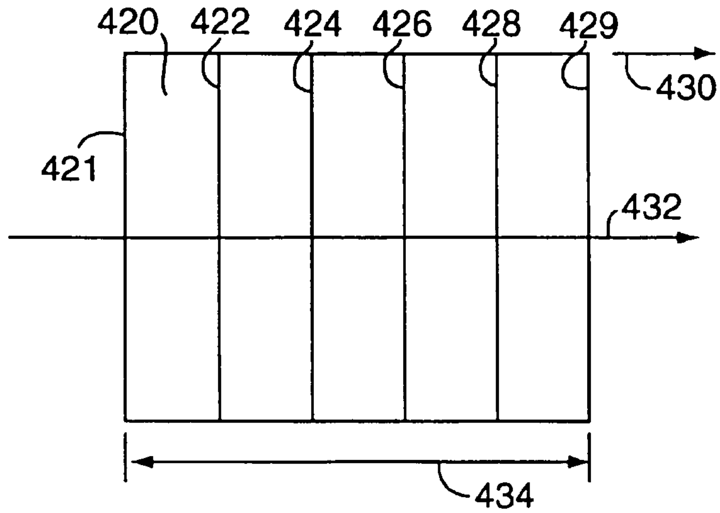


FIG. 23a

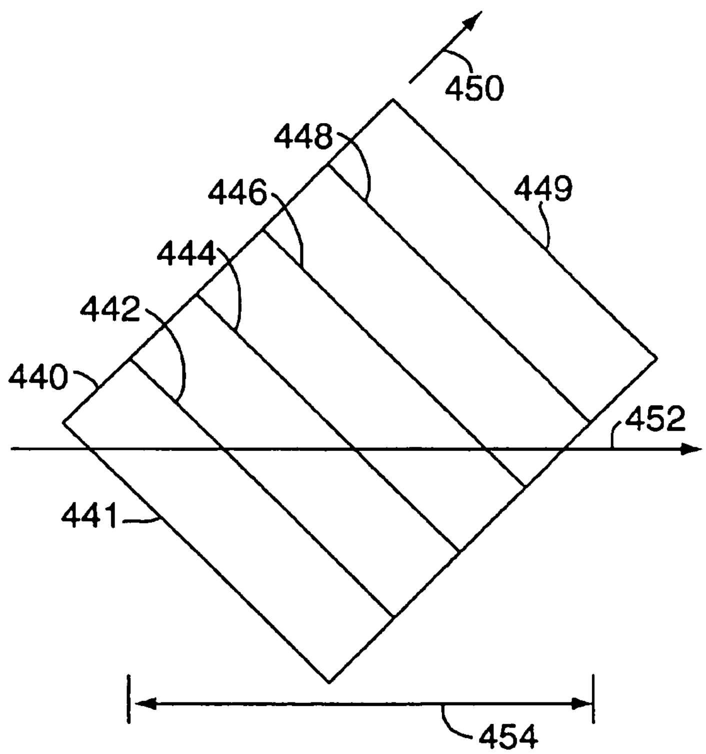


FIG. 23b

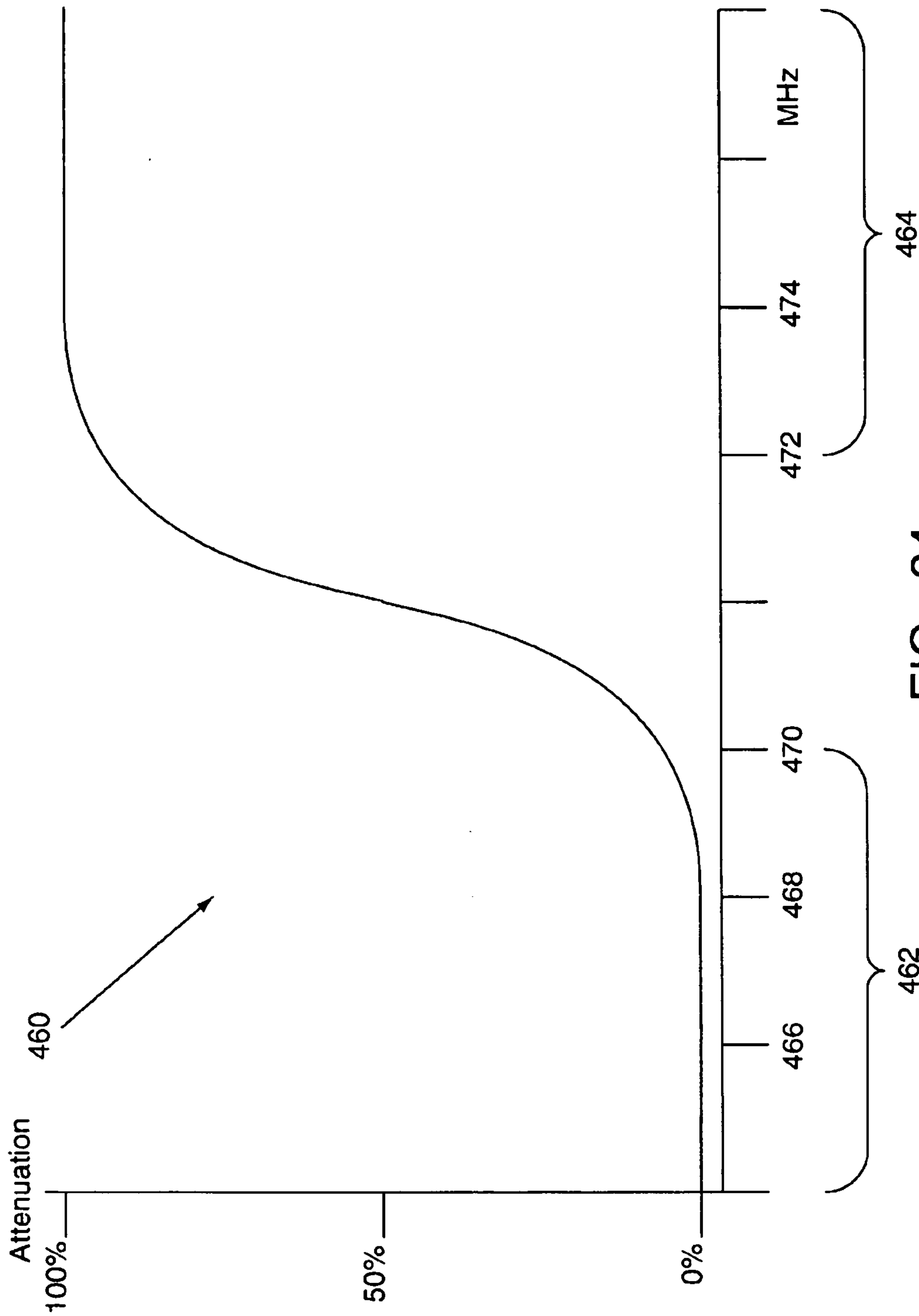


FIG. 24

METHOD AND APPARATUS FOR EVALUATING THE PERFORMANCE CHARACTERISTICS OF ENDOSCOPES

CROSS REFERENCE TO RELATED APPLICATIONS

Some of the matter contained herein is disclosed in U.S. patent application Ser. No. 08/822,330, entitled "METHOD AND APPARATUS FOR PERFORMING MODULATION TRANSFER FUNCTION TESTS ON ENDOSCOPES" (Attorney Docket No. 5509-02); U.S. patent application Ser. No. 08/821,601, entitled "APPARATUS FOR EVALUATING THE PERFORMANCE CHARACTERISTICS OF ENDOSCOPES" (Attorney Docket No. 5509-03); and U.S. patent application Ser. No. 08/822,283, entitled "AUTOMATED METHOD AND APPARATUS FOR EVALUATING THE PERFORMANCE CHARACTERISTICS OF ENDOSCOPES" (Attorney Docket No. 5509-04), each of which is being filed on even date herewith, is assigned to the Assignee of the present invention, and is hereby expressly incorporated by reference as part of the present disclosure.

FIELD OF THE INVENTION

The present invention relates to systems for testing endoscopes, and more specifically to systems for evaluating the optical performance characteristics of fiber optic endoscopes.

BACKGROUND OF THE INVENTION

A typical endoscope comprises a cylindrical stainless steel case enclosing a bundle of optical fibers extending between a distal end (tip end) and proximal end of the endoscope for transmitting light through the endoscope. A fiber optic cable delivers light from a light source into the case through an aperture situated near the proximal end of the endoscope. The optical fibers transmit the light through to the distal end, where the light exits the endoscope and illuminates the area near the distal end. The endoscope in turn transmits an image of that area through a rod and lens system to an eyepiece lens at the proximal end. A video camera coupled to the eyepiece converts the image into electronic signals and transmits the signals to a video monitor, where the image is displayed.

Endoscopes are used most often in "minimally invasive surgery", in which an endoscope is inserted into a patient, allowing a surgeon to illuminate and view the interior of the patient with minimal penetration. The use of endoscopic surgery is growing, in large part because it is generally safer and less expensive than conventional surgery, and patients tend to require less time in a hospital after endoscopic surgery. Conservative industry experts estimate that about 4 million minimally invasive procedures were performed in 1996. As endoscopic surgery becomes more common, there is an increasing need to accurately evaluate the performance characteristics of endoscopes.

To obtain a true measure of the performance of an endoscope, both the lens and the optical fibers should be evaluated. For example, some optical fibers may be damaged and only partially transmit light. In addition, the lens may distort images or blur the sharpness of image colors. These and other shortcomings in the optical performance of endoscopes may be the result of imperfections in the manufacturing process and/or may develop as the endoscope is used over time.

An apparatus for evaluating the performance characteristics of endoscopes would be able to validate claims made by

endoscope vendors about the capabilities of their products. Accordingly, such an apparatus would be advantageous for the purchasers and users of endoscopes. In addition, such an apparatus would be of great use in evaluating disposable endoscopes, which currently have an average life of about 20 to 30 uses. An apparatus for evaluating the performance characteristic of endoscopes would be able to determine when a disposable endoscope is so degraded that it should be discarded.

Furthermore, an endoscope may be adequate for one surgical procedure but inadequate for another which requires more precision, such as when a patient is bleeding. Currently, an endoscope which is suspected of having any deficiency must be removed from service and sent for repair, which can be both costly and time consuming. An apparatus for evaluating the performance characteristics of endoscopes would preferably be able to identify endoscopes which are appropriate for one type of procedure although inadequate for another.

Such an apparatus would also be most advantageous in a program of preventative endoscope maintenance. Endoscopes cost thousands of dollars, and typically require repairs at least about twice per year which can cost several thousand dollars per repair. There is a need for a tool for evaluating the performance characteristics of endoscopes, thereby verifying if repairs have been effective.

An apparatus for evaluating endoscope performance ideally would also be able to store the results of past tests and evaluations, thereby allowing the system to evaluate changes in endoscope performance after repair operations and over the lifetime of the endoscope. In addition, such information on changes in endoscope performance would be useful in predicting changes in the performance of other endoscopes before their performance degrades. This would help predict future endoscope needs.

The present inventors are not aware of any commercially available tools for use in a clinical environment which quantitatively assess the performance characteristics of endoscopes.

A further complication is that endoscopes vary in length, diameter and tip angle, which is the angle between the direction of view and the longitudinal axis of the endoscope. A system for evaluating endoscope performance would ideally also be able to accommodate endoscopes which have varying optical and/or physical characteristics.

Accordingly, it is an object of the present invention is to provide a method and apparatus for evaluating the optical performance characteristics of fiber optic endoscopes.

SUMMARY OF THE INVENTION

The present invention is directed to an apparatus and method for performing tests on the fiber optic path and the lens system of an endoscope, and in turn evaluating the optical performance of the endoscope in dependence on the results of the tests.

According to the present invention, a beam of light defining a predetermined intensity pattern is transmitted through the endoscope from a first end of the endoscope through a second end, and signals are generated indicative of the optical intensity of the transmitted beam at each of a plurality of predetermined locations within the beam. A second set of signals indicative of one or more performance characteristics of the endoscope are generated in response to the intensity signals and to signals indicative of the test type.

Preferably, a plurality of targets are employed to each generate a predetermined intensity pattern defining either a

uniform intensity, or an intensity which varies periodically, such as a sinusoidal-varying medium, in a predetermined direction across the transmitted beam. In the preferred embodiment of the invention, the targets are selected to perform each of the following tests: (i) a light loss test, (ii) a reflective symmetry test, (iii) a lighted fibers test, (iv) a geometric distortion test, and (v) a modulation transfer function (MTF) test. A video system generates signals indicative of the optical intensity of the beam after transmission through the endoscope at each of a plurality of predetermined locations within the beam. The video signals are in turn evaluated in accordance with the selected tests in order to provide graphical and numerical indicia of the optical performance characteristics of the endoscope.

One advantage of the apparatus and method of the present invention is that both the lens and optical fibers of an endoscope are tested and evaluated in order to accurately and quantitatively assess the performance characteristics of the endoscope.

Other advantages of the present invention will become apparent in view of the following detailed description and accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic illustration of an apparatus for evaluating the optical performance characteristics of fiber optic endoscopes in accordance with the present invention.

FIG. 2 is a perspective view of a test station of the apparatus of FIG. 1 for accommodating endoscopes of differing optical and physical characteristics, such as differing tip angles, lengths and diameters, and with parts removed for clarity.

FIG. 3*a* is a perspective view of the carrier of the test station of FIG. 2 and the associated targets for performing the light loss, reflective symmetry, geometric distortion, lighted fibers and modulation transfer function (MTF) tests on the endoscopes.

FIG. 3*b* is a partial cross-sectional view of the carrier of FIG. 3*a* illustrating the target for performing the MTF test in further detail.

FIG. 4 is a flow chart illustrating conceptually the procedural steps for performing a light loss test on the endoscopes in the apparatus of FIG. 1.

FIG. 5 is a flow chart illustrating conceptually the procedural steps for performing a reflective symmetry test on the endoscopes in the apparatus of FIG. 1.

FIG. 6 is a flow chart illustrating conceptually the procedural steps for performing a lighted fibers test on the endoscopes in the apparatus of FIG. 1.

FIG. 7 is a flow chart illustrating conceptually the procedural steps for performing a geometric distortion test on the endoscopes in the apparatus of FIG. 1.

FIG. 8 is a flow chart illustrating conceptually the procedural steps for performing a MTF test on endoscopes in the apparatus of FIG. 1.

FIG. 9A is an exemplary graph illustrating the intensity of a light beam generated by the light source of the apparatus of FIG. 1 before transmission through an exemplary endoscope.

FIG. 9B is an exemplary graph illustrating the intensity of a light beam generated by the light source of the apparatus of FIG. 1 after transmission through an exemplary endoscope.

FIG. 10 is an exemplary display of a graphical user interface provided by a computer of the apparatus of FIG. 1 illustrating a selection of tests that may be performed on an endoscope in accordance with the invention.

FIG. 11 is an exemplary display of a graphical user interface provided by the computer of FIG. 1 for evaluating the results of a light loss test.

FIG. 12 is an exemplary display of a graphical user interface provided by the computer of FIG. 1 for evaluating the results of a reflective symmetry test.

FIG. 13 is another exemplary display of a graphical user interface provided by the computer of FIG. 1 for evaluating the results of a reflective symmetry test.

FIG. 14 is another exemplary display of a graphical user interface provided by the computer of FIG. 1 for evaluating the results of a reflective symmetry test.

FIG. 15*a* is an exemplary display of a graphical user interface provided by the computer of FIG. 1 for evaluating the results of a lighted fibers test.

FIG. 15*b* is another exemplary display of a graphical user interface provided by the computer of FIG. 1 for evaluating the results of a lighted fibers test.

FIG. 16 is another exemplary display of a graphical user interface provided by the computer of FIG. 1 for evaluating the results of a lighted fibers test.

FIG. 17 is an exemplary display of a graphical user interface provided by the computer of FIG. 1 for evaluating the results of a geometric distortion test.

FIG. 18 is another exemplary display of a graphical user interface provided by the computer of FIG. 1 for evaluating the results of a geometric distortion test.

FIG. 19 is an exemplary display of a graphical user interface provided by the computer of FIG. 1 for evaluating the results of an MTF test.

FIG. 20 is another exemplary display of a graphical user interface provided by the computer of FIG. 1 for evaluating the results of an MTF test.

FIG. 21 is an exemplary graph illustrating the definition of modulation at a location within an image transmitted through an endoscope.

FIG. 22 is a schematic illustration of the distal end of an exemplary endoscope spaced apart from a semi-transparent medium for purposes of performing the MTF test in the apparatus of FIG. 1 in accordance with the present invention.

FIG. 23*a* is an exemplary, schematic illustration of the relative orientation between a semi-transparent medium used to perform the MTF test in accordance with the present invention and a scan direction parallel to the direction of variation in the transmittance of the medium.

FIG. 23*b* is an exemplary, schematic illustration of another semi-transparent medium used to perform the MTF test in accordance with the present invention and having an orientation relative to the scan direction different than the orientation of FIG. 23*a*.

FIG. 24 is an exemplary graph illustrating in simplified form the attenuation characteristics of a low-pass filter.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The preferred embodiment of the present invention is embodied in a low-cost endoscope evaluation system which accommodates endoscopes of different tip angles, lengths and diameters, performs tests on the endoscopes, and in turn evaluates the optical performance of the endoscopes in dependence on the results of the tests. The preferred embodi-

ment of the invention furthermore performs a selection of tests which evaluate the optical performance of both the optical fibers and lens of an endoscope, and thereby may provide a relatively accurate assessment of the effectiveness of a repair operation performed on an endoscope, as well as determine and record changes in the optical performance characteristics of an endoscope over its lifetime.

In FIG. **1**, an apparatus embodying the present invention for performing tests on endoscopes and for evaluating the optical performance of the endoscopes in dependence on the results of the tests is indicated generally by the reference numeral **10**. The apparatus **10** comprises a test station **12** including an adjustable mounting arm **14** for receiving and retaining an endoscope to be tested, and a carrier **16** for positioning a selected target under the distal end (tip) of the endoscope for performing a respective test.

A variable, high-intensity light source **18**, such as a xenon arc lamp or a halogen bulb, delivers light along a fiber optic cable **20** which is detachably connected to the endoscope through an aperture situated near its proximal end. In the currently preferred embodiment, the light source **18** is a variable xenon short-arc lamp, such as the 150 watt lamp sold under model no. 610 by Karl Storz Endoscopy-America Inc. of Culver City, Calif. As is described further below, during certain tests the fiber optic cable **20** is detached from the endoscope and re-positioned to directly illuminate a target on the carrier **16**. The test station **12** and the position of the fiber optic cable **20** during each of the tests performed on a typical endoscope are described in detail below.

A video system **22** generates signals indicative of the image which is projected through the eyepiece at the proximal end of the endoscope. In the preferred embodiment, the video system **22** comprises a charge-coupled device (CCD) video camera **24** coupled to the eyepiece and a video signal processor **26** coupled to the camera. As is known in the art, the CCD video camera records an image by storing charges in a plurality of semiconductor potential wells, thereby defining a two-dimensional array of charges which each correspond to the intensity at a point in the transmitted image. The video signal processor **26** transfers the charges out of the wells and thereby generates time-varying video signals indicative of the recorded image. The CCD video camera **24** is coupled to the endoscope eyepiece with an adjustable vice **28** having a lens system with both zoom and focus control rings. Thus, the projected image may be properly zoomed and focused through the vice lens system **28** before it is recorded by the camera **24**.

The video system **22** transmits the signals indicative of the image through a BNC connector to a standard video monitor **30** which displays the image, and to a desktop computer **32** which processes the signals in accordance with the present invention, as is described further below. In the currently-preferred embodiment, the computer **32** is an Intel Pentium™ microprocessor-based desktop computer which includes known computer software and peripheral devices as is necessary for its operation, such as an operating system, a keyboard, a hard disk, random access memory (RAM), a computer monitor and a mouse. The computer **32** further includes a frame grabber card (not shown), which is an analog-to-digital converter for receiving the image signals from the video system **22** and generating in dependence thereon digital signals indicative of the image. The frame grabber card thus translates the image signals from the format of the video system **22** to a digital format which the computer's microprocessor can accept and manipulate. The digital signals generated by the frame grabber card are preferably in the format of a 512 by 512 array of pixel intensities, and thus the number of pixels generated by the card is approximately determined as follows: 512×512=262,144 pixels.

The frame grabber card is preferably a "plug-in card" which is detachably connected to the system bus of the computer **32** in a known manner. The frame grabber card may be implemented with an "RT Mono"™ video capture board, sold by Digital Vision, Inc. of Dedham, Ma., and driver software sold by ViewPoint Solutions of Rochester, N.Y. for providing an interface between the video capture board and the standard Pentium™-based computer. Alternatively, the frame grabber card may be implemented with an IMAC PCI-1408 video capture board, sold by National Instruments of Austin, Tex. IMAQ Vision software and NI-IMAQ driver software, also sold by National Instruments, may provide the interface between the IMAC PCI-1408 video capture board and the standard Pentium-based desktop computer.

The computer **32** is coupled in a known manner to a standard printer **34** for printing images processed by the computer. In the preferred embodiment, the printer **34** is a laser printer having a resolution of at least about 600 dots per inch (dpi).

Turning to FIG. **2**, the test station **12** comprises a frame **36** including an upstanding arm support **38**, and a carrier support **40** defining a horizontal support surface. As indicated by the arrows in FIG. **2**, the mounting arm **14** is pivotally coupled to the arm support **38** and the angular position of the arm is adjustable relative to the carrier support **40** in order to accommodate endoscopes of all possible tip angles. In the preferred embodiment, the mounting arm **14** accepts endoscopes having outer diameters within the range of approximately 1.9 through 10.0 millimeters, lengths within range of approximately 4 inches through 13 inches, and tip angles within the range of approximately 0 degrees through 120 degrees.

As shown in FIG. **2**, the carrier **16** is mounted on the carrier support **40** adjacent to the mounting arm **14** and is moveable relative to the mounting arm along rails **31** in order to adjust the position of the carrier relative to an endoscope on the mounting arm. As is described further below, the carrier **16** includes a plurality of targets, each for performing a respective test to evaluate the optical performance of the endoscopes. The carrier support **40** defines an aperture **42** extending through the support surface immediately below the base of the mounting arm. In the preferred embodiment of the test station, the aperture **42** is approximately circular and defines a diameter of approximately 1.9 inches.

As shown schematically in FIG. **1**, directly beneath the aperture **42** and fixed to the underside of the carrier support **40** is a fiber optic cable holder **44** of a type known to those of ordinary skill in the pertinent art. The cable holder **44** receives and retains the fiber optic cable **20** in order to transmit a beam of light from the light source **18** through the aperture **42** to the distal end or tip of an endoscope being tested. A collimating lens **46** is fixed to the underside of the carrier support **40** and covers the aperture **42** in order to collimate the light beam projected through the aperture.

As illustrated in FIG. **3***a*, in the preferred embodiment there are four targets mounted on the carrier **16**, each of which is used in at least one of five tests for evaluating the performance of the endoscope and described in detail below. The term "target" is used herein to broadly describe any of the various devices used for receiving and/or reflecting a transmitted beam as part of each of the tests for evaluating

the performance characteristics of the endoscopes, as described further below.

The first target **47** is a photometer sensor which is coupled to a photometer **50** for measuring the intensity of light received by the sensor. A fixture **52** including a base **54** and three upstanding legs **56** is removably mounted above the photometer sensor **47** for detachably connecting the fiber optic cable **20** to the base in order to illuminate the sensor. As described in the above-mentioned co-pending patent application, the upstanding legs **56** define a predetermined length so that the distance between the base **54** and the sensor **50**, and thus the distance between the end of the fiber optic cable **20** and the sensor, is approximately equal to the distance between the photometer sensor and the distal end of an endoscope supported on the mounting arm. In the currently-preferred embodiment, this predetermined distance is approximately two inches.

The second target **58**, which is used in two tests in the preferred embodiment, defines a nonspecular reflective surface **60**, such as a Kodak R27, 90% reflectance card or a white sheet of paper. As is known in the art, a nonspecular reflective surface like the surface **60** is one which does not form a mirror-like reflected image, but rather diffuses the reflected light. A transparent film **62** having a printed reference pattern **63** is overlaid on the reflective surface **60** during at least one test. The reference pattern **63** printed on the transparent film **62** defines a number of reference points having a predetermined separation distance. As shown is FIG. 3*a*, the reference pattern is preferably a black, rectangular grid defining two sets of parallel lines spaced approximately 0.2 inches apart, wherein each of the first set of lines is perpendicular to each of the second set of lines. The reference pattern thus defines a set of squares having approximately 0.2 inch sides.

The third target **64** defines a substantially mirror-like surface **65**, and is preferably a circular reflector plate formed of a material having a reflectance preferably within the range of approximately 5% and approximately 40% reflectance, such as Lucite™, which is laid over a black background to provide the mirror-like quality. The surface **65** thus creates a specular (mirror-like) reflection. The reflectance of the surface **65** is selected to minimize the reflection of incident light, and thereby maintain the intensity of the light reflected back through any damaged fibers below a predetermined intensity level. As is described below, damaged fibers may be identified by their inability to transmit light having an intensity below a predetermined level. The substantially mirror-like surface **65** rests on three adjustable legs **61**, allowing precise control over the separation between the endoscope tip and the reflective surface.

The fourth target is a semi-transparent medium **48**, such as a film, and defines a transmittance which varies periodically along a predetermined direction within the medium. A beam of light which is filtered through the semi-transparent medium **48** will therefore have an intensity which varies periodically along the predetermined direction within the beam. In the preferred embodiment, the semi-transparent medium **48** has a transmittance which varies sinusoidally along the semi-transparent medium in a first direction, and which is substantially constant along the medium in a second direction transverse to the first direction. Also in the preferred embodiment, the sinusoidally-varying transmittance of the medium defines a spatial frequency of one cycle per millimeter (cycles per unit length), and is preferably of the type sold by Sine Patterns, Inc. of Penfield, N.Y.

As shown in FIG. 3*b*, an approximately circular aperture **49** is formed through the carrier **16**, a diffusing opal glass plate **55** is superimposed over the aperture, a white plastic translucent sheet **57** is superimposed over the glass plate, and the semi-transparent medium **48** is seated over the plastic sheet. As is described further below, when performing the MTF test the carrier **16** is positioned to align the circular aperture **49** with the aperture **42** of the carrier support **40**, and the free end of the fiber optic cable **20** is mounted beneath the aperture **42** to transmit a beam through the apertures, and in turn through the glass plate **55**, white plastic sheet **57** and semi-transparent medium **48**. The glass plate **55** and plastic sheet **57** together diffuse the beam from the fiber optic cable, creating a beam of substantially uniform intensity, and the semi-transparent medium **48** in turn filters the substantially uniform intensity beam to generate a beam which varies approximately sinusoidally along the first direction.

A black paper mask **59** defining a plurality of apertures is preferably inserted between the semi-transparent medium **48** and the white plastic sheet **57** in order to block light transmission through portions of the medium, and thereby enhance selected points in an image corresponding to the non-masked (illuminated) portions of the medium. As is described further below, each aperture of the black paper mask **59** defines a respective portion of the transmitted beam image within which the MTF is measured.

Test Performance

As indicated above, the following five tests are preferably performed with the apparatus of the invention in order to evaluate both the optical fibers and lens system of an endoscope: (i) light loss test, (ii) reflective symmetry test, (iii) lighted fibers test, (iv) geometric distortion test, and (v) MTF test. The details of each test, along with the preferred methods for analyzing the results of these tests to thereby evaluate the performance characteristics of the endoscopes, are hereinafter described.

FIG. **4** illustrates a flow chart **66** for performing the first test (light loss test) which is directed to measuring the reduction in the intensity of light after transmission through an endoscope. In general, the test comprises measuring two quantities: the intensity of light which exits the fiber optic cable ("light in") and the intensity of light which exits the fiber optic cable and is transmitted through the endoscope ("light out").

In performing the light loss test, the light source **18** (FIG. **1**) is activated (step **68**), set to a selected intensity level, and preferably left active for a predetermined period of time in order to allow the light source to reach the selected intensity level. In the preferred embodiment, the predetermined intensity level is determined such that the intensity of light transmitted through the endoscope is within the preferred operating range of the photometer sensor target **47**, and the predetermined period of time is at least approximately ten minutes. The free end of the fiber optic cable **20** (FIG. **1**) is then coupled to the fixture **52** (FIG. 3*a*) and thereby spaced a predetermined distance above the photometer sensor target **47** (which is approximately equal to the distance between the tip end of the selected endoscope supported on the mounting arm and the target) to thereby illuminate the sensor (step **70**). The photometer intensity reading is then recorded and designated "light in" (step **72**).

After the "light in" intensity is recorded, the cable **20** is removed from the carrier fixture **52** (FIG. 3*a*) and attached to the proximal end of the endoscope supported on the mounting arm **14** (step **74**), as indicated in FIG. **1**. The angular position of the mounting arm **14** is adjusted relative to the photometer sensor target **47** to correspond to the actual tip angle of the endoscope tested. The position of the carrier

16 is also adjusted so that the photometer sensor target 47 is positioned directly underneath, or aligned with the endoscope tip and spaced the predetermined distance (approximately two inches) from the endoscope tip (step 76). In the final step of the light loss test, the photometer intensity reading is recorded (step 78), and this intensity reading is designated the "light out". Both the "light in" and "light out" readings are recorded and used, as described below, in measuring the reduction in the intensity of light after transmission through the endoscope.

FIG. 5 illustrates a flow chart 80 for performing the second test (reflective symmetry test) which is directed to measuring the reflective symmetry of light which exits the eyepiece of the endoscope. When an ideal endoscope transmits an image of uniform intensity from its tip end to its proximal end, the transmitted image is approximately circularly symmetrical about the center of the transmitted image. Thus, the intensity in the center of the transmitted image is greatest, and the intensity decreases at locations in the transmitted image spaced radially from the center. All points which are equally distant from the center of the transmitted image have approximately equal intensities, and the intensity at the periphery of the transmitted image is lowest. In actual (nonideal) endoscopes, deviation from the circular symmetry of the transmitted image indicates damaged optical fibers.

In performing the reflective symmetry test, the light source 18 (FIG. 1) is activated (step 82) and set to a selected intensity level. In the preferred embodiment, the predetermined intensity level is determined such that the intensity of light transmitted through the endoscope is within the preferred operating range of the video system 22 (FIG. 1). The fiber optic cable 20 (FIG. 1) is attached to the endoscope supported on the mounting arm (step 84), and the carrier is positioned so that the second target, the reflective surface 65, is positioned directly underneath, or aligned with the endoscope tip (step 86). The video system 22 is then focused on the reflective surface 65 (step 88). A preferred method for focusing the video system is to overlay a reference pattern film, such as the transparent film 62 (FIG. 3*a*), on the reflective surface 65, set the adjustable vice 28 connecting the video system 22 (FIG. 1) to the endoscope to its maximum zoom setting, and then adjust the focus ring of the vice to bring the reference pattern into focus. Once the video system 22 is focused, the reference pattern film 62 is removed from the reflective surface 65.

As discussed above, the center of the transmitted image should have the highest intensity. However, if the endoscope is not oriented properly (i.e. if the tip angle is not substantially equal to the angle of the mounting arm), the point of highest intensity in the transmitted image will not coincide with the center of the transmitted image. Accordingly, if necessary, the angular position of the mounting arm must be adjusted until the approximate center of the transmitted image has the highest intensity (step 90). Unfortunately, endoscope tip angles are generally not held to a tight tolerance, and thus the proper angle of the mounting arm generally cannot be set based only on the purported (nominal) tip angle of the endoscope.

A preferred method for orienting the endoscope is to adjust the angle of the mounting arm 14 while the video system 22 displays the transmitted image on the video monitor 30 (FIG. 1) or on a computer monitor of the computer system 32 (FIG. 1). In this manner, a human operator can adjust the mounting arm 14 by viewing the transmitted image on the monitor and simultaneously moving the arm until the center of the transmitted image coincides with the point of highest intensity.

Once the endoscope is properly oriented, the frame grabber card stores the transmitted image and generates digital signals indicative of the image (step 92). It is preferable that the frame grabber card have an adjustable range of intensities which it can accept and translate to digital format. It is most preferable that in each test the frame grabber card generates signals indicative of white pixels for the highest intensities in the stored image, and signals indicative of black pixels for the lowest intensities in the stored image. In this manner, the frame grabber card produces pixels having intensities which span approximately the entire output range of the card, which in turn improves resolution and facilitates evaluation of the test results. The computer system 32 processes the digital signals (pixels) when evaluating the endoscope, as described further below.

FIG. 6 illustrates a flow chart 100 for performing the third test (lighted fibers test) which is directed to measuring the ability of the endoscope optical fibers to transmit low-intensity light. The light source 18 (FIG. 1) is activated (step 102) and set to a selected intensity level. In the preferred embodiment, the predetermined intensity level is determined such that the intensity of light transmitted through the endoscope is within the preferred operating range of the video system 22 (FIG. 1). The fiber optic cable 20 (FIG. 1) is attached to the proximal end of the endoscope supported on the mounting arm (step 104), and the carrier is positioned so that the third target defining the substantially mirror-like surface 65 is positioned directly underneath, or aligned with the endoscope tip at a relatively close distance selected to produce a focused, specular reflection of the lighted optical fibers at the endoscope eyepiece (step 106). This distance is typically less than approximately 0.25 inches. The frame grabber card stores the transmitted image and generates digital signals indicative of the image (step 108) which the computer 32 processes when evaluating the image data.

FIG. 7 illustrates a flow chart 110 for performing the fourth test (geometric distortion test) which is directed to measuring the degree to which the endoscope geometrically distorts an image. Distortion at a point in the transmitted image is defined as the ratio of the magnification at that point to the magnification at the center of the transmitted image. A preferred method for measuring distortion is to transmit through the endoscope an image of a plurality of equally-sized squares, and to then measure and compare the diagonal lengths of the corresponding squares in the transmitted image.

The light source 18 (FIG. 1) is activated (step 112) and set to a selected intensity level. In the preferred embodiment, the predetermined intensity level is determined such that the intensity of light transmitted through the endoscope is within the preferred operating range of the video system 22 (FIG. 1). The fiber optic cable 20 (FIG. 1) is attached to the proximal end of the endoscope supported on the mounting arm (step 114), and the carrier is positioned so that the second target 58 defining the reflective surface 60 is positioned directly underneath, or aligned with the endoscope tip (step 116). In addition, the transparent film 62 with the reference pattern 63 is overlaid on the reflective surface 60 and the video system 22 is then focused on the pattern (step 118). A preferred method of focusing the video system 22 is to set the adjustable vice to maximum zoom, and to then adjust the focus ring of the vice to bring the reference pattern into focus. Once the video system 22 is focused, the frame grabber card stores the transmitted image and generates digital signals indicative of the image (step 120). The computer 32 processes the digital signals when evaluating the endoscope, as is described further below.

FIG. 8 illustrates a flow chart 130 for performing the fifth test (MTF test) which is directed to measuring the modulation transfer function (MTF) of the endoscope at a predetermined spatial frequency, which is equivalent to measuring the modulation transfer ratio (MTR) of the endoscope while it transmits an image having an intensity which varies along a direction at the predetermined spatial frequency.

An image's modulation is correlated with the contrast (sharpness) of the image. The modulation at a location in an image is defined by the maximum intensity and the minimum intensity at that location as follows:

$$\text{modulation}=(\text{maximum intensity}-\text{minimum intensity})\div(\text{maximum intensity}+\text{minimum intensity})$$

As used herein, the terms "maximum intensity" and "minimum intensity" refer to the local maxima and minima, respectively, of a cycle in the periodically-varying intensity.

An endoscope reduces the modulation of a transmitted image, so that the transmitted image is not as sharp as the image received at the endoscope tip. The MTR is a measure of the change in an image's modulation after transmission through the endoscope. The MTR is defined as follows:

$$MTR=\text{modulation of image after transmission}\div\text{modulation of image before transmission}$$

FIGS. 9A and 9B illustrate the maximum and minimum intensities in an image before and after transmission through an endoscope, respectively. The graph 140 in FIG. 9A represents the sinusoidally-varying intensity of an image which is received at the endoscope tip (i.e. before transmission through the endoscope). Points 146 and 150 have a maximal intensity 142, while a point 148 has a minimal intensity 144. The intensity variation 143 in the image before transmission is the difference between the maximal intensity 142 and the minimal intensity 144.

The graph 160 in FIG. 9B represents the sinusoidally-varying intensity of an image after transmission through the endoscope. Points 166 and 170 have a maximal intensity 162, while a point 168 has a minimal intensity 164. The points 166, 168 and 170 of the transmitted image (FIG. 9B) correspond respectively to the points 146, 148 and 150 of the received image (FIG. 9A). The intensity variation 163 in the image after transmission is the difference between the maximal intensity 162 and the minimal intensity 164.

The intensity variation 163 in the image after transmission is less than the intensity variation 143 in the image before transmission. In other words, transmission through the endoscope reduces the sharpness of the image. The MTF test is directed to measuring this reduction in sharpness at different locations in the transmitted image.

Referring again to FIG. 8, in performing the MTF test, the light source 18 (FIG. 1) is activated (step 132) and set to a selected intensity level. In the preferred embodiment, the predetermined intensity level is determined such that the intensity of light transmitted through the endoscope is within the preferred operating range of the video system 22 (FIG. 1). The free end of the fiber optic cable 20 (FIG. 1) is attached to the fiber optic cable holder 44 (FIG. 1) mounted below the aperture 42 of the carrier support 40 (step 134), in order to transmit a light beam through the aperture. The carrier 16 is then positioned so that the fourth target, the semi-transparent medium 48, is positioned directly underneath the endoscope tip and above the carrier support aperture 42 (step 136), thereby filtering the beam projected from the fiber optic cable and transmitting the filtered beam through the endoscope. The frame grabber card stores the transmitted image and generates digital signals indicative of the image (step 138).

In summary, each of the tests described above are preferably performed on each endoscope in order to provide test results comprising a set of signals indicative of intensities at predetermined locations in a beam of light transmitted through the endoscope. As hereinafter described, the system of the invention preferably further generates a second set of signals responsive to the test result signals and which is indicative of the performance characteristics of the endoscope. The manner in which the second set of signals is generated depends on the particular test used to generate the corresponding test result signals.

Test Result Evaluation

For each of the above-described tests, the computer system 32 (FIG. 1) receives the signals indicative of the beam intensities, and generates the second set of signals in accordance with the intensity signals and further in accordance with signals indicative of the test type. FIG. 10 shows an exemplary display 180 of a graphical user interface (GUI) generated and displayed on the monitor of the computer system 32. As is known in the art, a GUI provides both a means for user input and a means for the computer system to display information. The GUI provides signals indicative of the type of test, typically in accordance with user commands such as the actuation of graphical buttons and switches. In the preferred embodiment, the GUI is implemented using LabVIEW® software sold by National Instruments of Austin, Tex. Accordingly, the various types of displays and input methods of the GUI described herein are those which are most easily implemented with LabVIEW® software. However, those skilled in the art will recognize that other types displays and input methods may be implemented, including other forms of graphical, textual and audio input and output.

The display 180 includes graphical "buttons" which the user actuates via mouse or keyboard actions in a manner known in the art. Upon actuation of a button 182, the GUI provides a second display (not shown) into which the user may enter information related to the endoscope being tested. Such information includes the endoscope identification code, manufacturer, diameter, length and tip angle, as well as any reported and observed problems with the endoscope. Further types of information may be included without departing from the scope of the present invention.

A graphical indicator 186 displays a message which indicates whether the endoscope supported on the mounting arm is untested, has passed a test, or has failed a test. Actuation of a button 187 signals that a new endoscope is to be evaluated, and that previously stored test results are therefore inapplicable to this endoscope. Accordingly, upon actuation of the button 187, the graphical indicator 186 displays a message indicating that the endoscope is untested.

Actuation of a button 184 provides a third display 200 shown in FIG. 11. The display 200 facilitates analysis of the results of the light loss test. As described above, performing the light loss test yields signals indicative of a Light-In and a Light-Out measurement from the photometer sensor 47. The ratio of these two intensities yields the light loss of the tested endoscope in units of Optical decibels (dB Optical) in accordance with the following relationship:

$$\text{Light Loss}=10\log(\text{Light-Out}/\text{Light-In})$$

The user provides the Light-In reading in a text entry region 202 and the Light-Out reading in another text entry region 204. Upon entry of valid numerical values in both text entry regions 202 and 204, the computer system 32 generates signals indicative of the entered readings, and in turn generates signals indicative of the Light Loss in accor-

dance with the above relationship. Finally, the computer system **32** displays a textual indication of the Light Loss in a display region **206**.

The displayed Light Loss allows the user to compare the endoscope under test with average or expected Light Loss values, which generally depend on the diameter of the endoscope. Typical values for Light Loss are about (−6±3) dB Optical for a 10 millimeter diameter endoscope, and about (−16±3) dB Optical for endoscopes with diameters between 2 and 4 millimeters.

Referring again to FIG. **10**, actuation of the buttons **188**, **189**, **192** and **194** initiates analyses of the results of the reflective symmetry test, MTF test, lighted fibers test and geometric distortion test, respectively. The analyses of the results of these four tests are directed generally to generating signals which are indicative of the degree to which the tested endoscope attenuates the intensity of the transmitted beam at predetermined locations within the beam.

Actuation of the button **188** initiates analysis of the results of the reflective symmetry test, and causes the GUI to provide a display of the type indicated by the reference numeral **210** of FIG. **12**. The display **210** includes a region **212** showing a graphical display of an intensity pattern of the transmitted beam. In the preferred embodiment, the region **212** defines a two-dimensional array of pixels, and each pixel has a color (e.g., a shade of gray) indicating the intensity of the transmitted beam at a location in the beam corresponding to the location of the pixel. Also in the preferred embodiment, a substantially white pixel indicates a location in the beam with the highest intensity relative to all pixels, while a substantially black pixel indicates a location in the beam with the lowest intensity relative to all pixels.

As shown in FIG. **12**, the region **212** defines a plurality of concentric regions, each defining a respective intensity range and corresponding to a respective region within the transmitted beam. In the preferred embodiment, the intensity of a respective concentric region is indicated by the shade of that region. The lighter the shade, the higher is the intensity of the region; and the darker the shade, the lower is the intensity of the region.

Referring to the exemplary graphical image shown in the region **212** of FIG. **12**, the region **212** defines an approximately oval central region **230**, three approximately concentric annular regions **232**, **234** and **236** progressively spaced outwardly from the central region in the radial direction, and a peripheral region **238** surrounding the outermost annular region **236**. The central region **230** contains pixels which are white, and thus defines the region within the beam of highest intensity. Typically, the pixels spaced radially outwardly from the central region **230** define progressively darker shades, and the pixels at the peripheral region **238** of the display are substantially black because they correspond to the periphery of the transmitted beam defining the lowest intensity. Although the exemplary graphical image shown in the region **212** defines five regions **230**, **232**, **234**, **236** and **238**, and thus the region **212** indicates five intensity ranges, those skilled in the art will recognize that a number of intensity ranges different than the five shown may be used without departing from the scope of the invention.

The region **212** further includes a vertical indicator bar **226** and a horizontal indicator bar **228** which may be moved horizontally and vertically, respectively, within the region **212** by appropriate user command (e.g. a mouse action or keyboard key press). Each bar **226** and **228** defines a plurality of collinear pixels in the display and, thus, corresponds to a plurality of approximately collinear locations within the transmitted beam.

The display **210** further includes a vertical cross-section display region **216** showing a graphical display indicative of the intensity of the transmitted beam in the approximately collinear locations defined by the vertical bar **226** of the region **212**. The intensity curve shown in the region **216** is formed by a plurality of pixels each having a vertical position corresponding to the vertical position of a pixel in the region **212** along the vertical bar **226**, and a horizontal position corresponding to the intensity of that pixel.

Similarly, the display **210** further includes a horizontal cross-section display region **214** showing a graphical display indicative of the intensity of the transmitted beam in the approximately collinear locations defined by the horizontal bar **228** of the region **212**. The intensity curve shown is formed by a plurality of pixels each having a horizontal position corresponding to the horizontal position of a pixel in the region **212** along the horizontal bar **228**, and a vertical position corresponding to the intensity of that pixel.

Upon actuation of a button **222** on the display **210**, a display **250** of the type shown in FIG. **13** is generated which includes a display region **252** comprising a three-dimensional image indicative of the intensity of the transmitted beam and corresponding to the image of the region **212** (FIG. **12**). A region **254** includes controls for adjusting the point-of-view of the three-dimensional image, and a region **256** includes controls for adjusting the scale of the three-dimensional image along three mutually-perpendicular directions (e.g., the x, y and z coordinate directions).

The three regions **212**, **214** and **216** (FIG. **12**) and the three-dimensional image (FIG. **13**) each provide an indication of the degree to which the transmitted image is circularly symmetrical, and thus the degree to which the intensity of the transmitted beam is symmetrical (or non-symmetrical) about its center. A user may be able to evaluate an endoscope based on this type of graphical feedback alone, and determine whether or not the endoscope is acceptable. However, as discussed below, the computer system **32** of the invention further provides an explicit indication of whether the tested endoscope passes a threshold standard for the reflective symmetry test.

Referring again to FIG. **12**, upon actuation of a button **224** on the display **210**, a display **268** of the type shown in FIG. **14** is generated. The display **268** indicates, for each of a plurality of intensity ranges, the number of pixels which correspond to that intensity. The display **268** includes a region **262** showing a histogram comprising a plurality of vertical bars. A region **260** comprising a plurality of text entry areas allows the user to define each intensity range by entering values defining the upper bounds of the intensity ranges. A region **258** provides a plurality of numerical values corresponding to the number of pixels included in each intensity range. And a region **265** provides a plurality of numerical values corresponding to the percentage of pixels included in each intensity range. Accordingly, the regions **258**, **262** and **265** display substantially the same information in three different formats.

A selector **264** is set by the user to select one of the intensity ranges. A textual display **266** indicates the percentage of pixels having an intensity within or above the range indicated by the selector **264**. For example, if the selector **264** is set to the second highest intensity range, the textual display **266** will indicate the percentage of pixels having an intensity included in either the second highest or highest intensity range.

A textual display **267** indicates whether the endoscope has passed the reflective symmetry test. A textual display **220** in FIG. **12** also indicates whether the endoscope has passed the reflective symmetry test. In accordance with the invention, an endoscope passes the reflective symmetry test if more than a predetermined percentage of pixels have an intensity greater than a predetermined or threshold intensity level. In the preferred embodiment, the predetermined percentage of pixels is approximately 30%, and the predetermined intensity is approximately 50% of the maximum possible pixel intensity, although these values may be changed using the display **268** as described above (FIG. **14**). As discussed above, the intensity of a pixel corresponds to an intensity of a location in the transmitted beam, which itself is defined by the degree to which the endoscope attenuates the intensity at that location. Thus, it is equivalent to say that an endoscope passes the reflective symmetry test if more than a predetermined number of locations in the transmitted beam have been attenuated by less than a predetermined attenuation.

Referring again to FIG. **10**, actuation of the button **192** initiates the analysis of the results of the lighted fibers test, and a display **270** of the type shown in FIG. **15***a* is generated. The display **270** is substantially similar to the display **210** of FIG. **12** for analyzing the results of the reflective symmetry test. The display **270** includes a region **272** showing a graphical display indicative of the intensity of the transmitted beam. The region **272** further includes a vertical indicator bar **286** and a horizontal indicator bar **288**. As discussed above with reference to the display **210** of FIG. **12**, the bars **286** and **288** each define a plurality of collinear pixels in the display and, therefore, a plurality of substantially collinear locations in the transmitted beam. The display **270** further includes a horizontal cross-section display region **274** corresponding to the horizontal bar **288** of the region **272** and showing the beam intensity at each point within the region **274** along the horizontal bar, and a vertical cross-section display region **276** corresponding to the vertical bar **286** of the region **272** and showing the beam intensity at each point within the region **276** along the vertical bar.

Upon actuation of a button **280** on the display **270**, a display **290** of the type shown in FIG. **15***b* is generated which includes a display region **292** comprising a three-dimensional image indicative of the intensity pattern of the transmitted beam and corresponding to the image of the region **272** (FIG. **15***a*). A region **294** includes controls for adjusting the point-of-view of the three-dimensional image, and a region **296** includes controls for adjusting the scale of the three-dimensional image along three mutually-perpendicular directions (e.g., the x, y and z coordinate directions).

The three-dimensional image **292** and the three display regions **272, 274** and **276** each provide an indication of the degree to which optical fibers in the endoscope are damaged and do not transmit light. A user may be able to evaluate the endoscope based on this type of graphical feedback alone, and determine whether or not the endoscope is acceptable. However, as discussed below, the computer system **32** of the present invention further provides an explicit indication of whether an endoscope being tested has passed the lighted fibers test.

Upon actuation of a button **282** in the display **270**, the GUI provides a display **297** of the type shown in FIG. **16**. The display **297** includes regions **306** and **308** which indicate, for each of a plurality of intensity ranges, the number of pixels which correspond to the respective intensity range. In the preferred embodiment, only two ranges are considered: intensities above a predetermined intensity ("on") and intensities equal to or below a predetermined intensity ("off"). The display **297** includes a selector **304** with which the user sets the predetermined intensity.

The display **297** also includes a selector **302** with which the user selects a value corresponding to a minimum threshold number of pixels. Another selector **300** allows the user to select a range around the selected minimum threshold number of pixels. If the actual number of pixels which are "on" is within this selected range, the endoscope is considered to have passed the lighted fibers test, and the computer system generates signals accordingly. A textual display **298** indicates whether the results of the lighted fibers test indicate that the endoscope has passed. The display **270** (FIG. **15**A) also includes a textual display **278** which indicates whether the results of the lighted fibers test indicate that the endoscope has passed.

As discussed above, the intensity of a pixel corresponds to an intensity of a location in the transmitted beam. The number of working fibers in the endoscope, which is correlated with the number of white pixels in the display region **272** (FIG. **15**A), depends on such factors as the endoscope's dimensions, the tip angle and the number of damaged optical fibers. As is also discussed above, the beam intensity at each location is defined by the amount which the endoscope attenuates the intensity at that location. Thus, it is equivalent to say that an endoscope has passed the lighted fibers test if more than a predetermined number of locations in the transmitted beam have been attenuated by less than a predetermined attenuation.

In the preferred embodiment described above, the predetermined intensity, the minimum threshold number of pixels, and the range around the selected minimum threshold number of pixels have been described as values which the user may select. However, those skilled in the art will recognize that that such values may be fixed and not alterable by the user. Such an embodiment may be preferable if necessary to prevent the user from altering values which define preferred threshold values, or the preferred range for such values.

Referring again to FIG. **10**, actuation of the button **194** initiates analysis of the results of the geometric distortion test, and causes the GUI to provide the display **310** of the type shown in FIG. **17**. The display **310** is substantially similar to the display **210** of FIG. **12** for analyzing the results of the reflective symmetry test, and includes a region **312** showing a graphical display indicative of an intensity pattern of the transmitted beam.

The region **312** further includes a vertical indicator bar **320** and a horizontal indicator bar **318** which may be moved horizontally and vertically, respectively, within the region **312** by appropriate user command. As discussed above with reference to the display **210** of FIG. **12**, each of the bars **318** and **320** define a plurality of approximately collinear pixels in the display and, therefore, a plurality of substantially collinear locations in the transmitted beam. The display **310** further includes a horizontal cross-section display region **314** corresponding to the horizontal bar **318** of the region **312** and showing the beam intensity at each point within the region **314** along the horizontal bar, and a vertical cross-section display region **316** corresponding to the vertical bar **320** of the region **312** and showing the beam intensity at each point within the region **316** along the vertical bar.

Upon actuation of a button **322** on the display **310**, a display is generated (not shown) which includes a display region comprising a three-dimensional image indicative of the intensity pattern of the transmitted beam and corresponding to the image of the region **312** (FIG. **17**). Like the

displays of FIGS. 13 and 15*b*, the display includes a region defining controls for adjusting the point-of-view of the three-dimensional image, and another region defining controls for adjusting the scale of the three-dimensional image along three mutually-perpendicular directions (e.g., the x, y and z coordinate directions).

The three-dimensional image and the three regions **312**, **314** and **316** each provide an indication of the degree to which the endoscope geometrically distorts the image at different locations in the transmitted beam. A user may be able to evaluate the endoscope based on this type of graphical feedback alone, and determine whether or not the endoscope is acceptable. However, as discussed below, the computer system **32** of the present invention further provides an explicit indication of whether an endoscope being tested has passed the geometric distortion test.

Upon actuation of a button **324** in the display **310**, the GUI provides a display **330** of the type shown in FIG. **18**. The display **330** includes indicators **332**, **334**, **336**, **338** and **340** which each indicate the degree of geometric distortion at a respective location within the transmitted beam. The degree of geometric distortion at each location is determined from the image of the reference pattern forming a part of the transmitted image. As discussed above, the reference pattern **63** (FIG. 3*a*) defines a set of equally-sized squares, and geometric distortion will cause the reference pattern in the transmitted image to define squares of different sizes or to otherwise distort the shape of one or more squares. Accordingly, the geometric distortion at a location is determined based on the length of the diagonal of the square at that location. In particular, the distortion value at a location is calculated in accordance with the following relationship:

$$\text{Distortion}=(S_1/S_2)-1$$

wherein S_1=the diagonal length of the square at the respective location; and

S_2=the diagonal length of the central square.

Each of the indicators **332**, **334**, **336**, **338** and **340** further indicates whether the results of the distortion calculation at the respective location indicates either a pass or fail condition. In the preferred embodiment, each distortion value is compared to a predetermined distortion threshold. Distortion values which are below the predetermined distortion threshold are considered "fail" values. If at least one of the plurality of distortion values is a fail value, the endoscope will typically fail the geometric distortion test. Textual displays **342** (FIG. **18**) and **325** (FIG. **17**) indicate whether the endoscope has passed the geometric distortion test.

Referring again to FIG. **10**, actuation of the button **189** initiates analysis of the results of the MTF test, and causes the GUI to provide a display **350** of the type shown in FIG. **19**. The display **350** is substantially similar to the display **210** of FIG. **12** for analyzing the results of the reflective symmetry test. The display **350** includes a region **352** showing a graphical display indicative of the intensity pattern of the transmitted beam, and regions **354** and **356** for displaying cross-sectional views of the display **352** defined by the bars **358** and **360**. With reference to the display region **352**, the apertures of the black paper mask **59** (FIG. 3*b*) each define a respective region **359** of the transmitted beam image within which the MTF is measured. In the preferred embodiment, and as shown in FIG. **19**, the MTF is measured at the approximate center of the transmitted image, and at select locations on the periphery of the transmitted image, including above center, below center, to the right of center, and to the left of center.

A button **362** on the display **350** allows generation of a three-dimensional image corresponding to the image of the display **352** and indicative of the intensity pattern of the transmitted beam. The three-dimensional image and the three regions **352**, **354** and **356** each provide an indication of the MTF at different locations in the transmitted image. A user may be able to evaluate the endoscope based on this type of graphical feedback alone, and determine whether or not the endoscope is acceptable. However, as discussed below, the computer system **32** of the present invention further provides an explicit indication of whether a tested endoscope has passed the MTF test.

Upon actuation of a button **364** in the display **350**, the GUI provides a display **370** of the type shown in FIG. **20**. The display **370** includes indicators **372**, **374**, **376**, **378** and **380** which each indicate the MTF at a respective one of the selected locations within the transmitted beam. As discussed above, the modulation at a respective location within the transmitted beam is defined as follows:

$$\text{modulation}=(\text{maximum intensity}-\text{minimum intensity})\div(\text{maximum intensity}+\text{minimum intensity});$$

and the MTR at the respective location in the transmitted image is further defined as follows:

$$MTR=\text{modulation of image after transmission}\div\text{modulation of image before transmission.}$$

As discussed above, the sinusoidally-varying medium **48** causes the intensity of the transmitted beam to vary sinusoidally along a predetermined direction in the beam, and the video signals generated by the video system **22** correspondingly vary sinusoidally with respect to time and thus are indicative of the intensity pattern of the transmitted image. The maximum and minimum intensities used in calculating the modulation are each measured with respect to an intensity of the video signal corresponding to a "black" (dark or unilluminated) intensity. Those skilled in the art will note that the signal intensity corresponding to "black" is different from the "back porch" level of the video signal, which is typically lower.

FIG. **21** depicts a graph **390** illustrating the definition of modulation at a location within a light beam. The graph **390** includes a curve **392** representing an intensity which varies sinusoidally along a predetermined direction. At a location defined by a range **394** along the predetermined direction, the intensity varies from a maximum intensity **396** at a distance **400** along the predetermined direction to a minimum intensity **398** at a distance **402** along the predetermined direction. Thus, the modulation at a location defined by the range **394** may be determined from the maximum intensity **396** and minimum intensity **398** in the manner defined above. In another embodiment, the maximum intensity used in the modulation determination is the average of the maximum intensities of two consecutive cycles, such as the intensities at distances **400** and **404**. Using an average of two maximum intensities accounts for maximum intensities which vary significantly among consecutive cycles, such as is common at the periphery of the transmitted image where the intensity sharply declines.

It is known in the art that the MTF value of a system is equal to the product of the MTF values of the components of the system. The above-described MTF values are generated in dependence on the signals generated by the frame grabber card, and represent the MTF value of the combination of the endoscope and the video system **22**. However, since the video system is typically optically superior to the endoscope, a fixed correction factor can be calculated for the video system and used in determining the MTF of the endoscope alone. According to "Video Engineering" by

Andrew Inglis, McGraw Hill, 1993, which is hereby expressly incorporated by reference as part of the present disclosure, a correction factor of approximately 0.96 is appropriate for video systems such as those used in the present invention. Furthermore, the precision micro-densitometer modulation calibration of the semi-transparent medium **48** also affects the MTF of the entire endoscope evaluation apparatus. The semi-transparent medium **48** provided by Sine Patterns, Inc. has a modulation calibration of 0.81366. Accordingly, the MTF value for the endoscope alone is determined by dividing the above-calculated MTF (which is equivalent to the MTR) by the following product: (0.96)*(0.81366).

Referring again to FIG. **20**, each of the indicators **372, 374, 376, 378** and **380** further indicates whether an MTF value indicates either a "pass" or "fail" condition. In the preferred embodiment, each MTF value is compared to a predetermined MTF threshold. MTF values which are below the predetermined MTF threshold are considered "fail" values. If at least one of the plurality of MTF values is a fail value, the endoscope has failed the MTF test. Textual displays **382** (FIG. **20**) and **366** (FIG. **19**) indicate whether the endoscope has passed the MTF test. In the preferred embodiment, for 10 millimeter diameter endoscopes with 0 degree tip angles, the MTF threshold at the center of the transmitted beam is approximately 0.70, and at other locations in the transmitted beam is approximately 0.20.

As is known in the art, a spatial frequency is defined by the number of cycles (transitions from a maximum intensity to a minimum intensity and back again) per unit of length. The semi-transparent medium **48** (FIG. 3*a*) is preferably implemented as the above-mentioned sinusoidally-varying medium having a spatial frequency of one cycle per millimeter. Thus, filtering a beam of light through this medium during the MTF test generates a beam having an intensity which varies approximately sinusoidally along a first direction in the generated beam at a spatial frequency of about one cycle per millimeter, and which is approximately constant along a second direction in the generated beam. The generated beam is transmitted through the endoscope and recorded by the video system **22** (FIG. **1**) as set forth above.

The video system **22** records the transmitted image in a conventional manner: the CCD camera sequentially scans in a horizontal scan direction from one end of the transmitted image to the other, defining a scan row, and the video system generates time-varying video signals indicative of a row of pixels for the scanned row. In other words, the video signals generated by the video system **22** correspondingly vary sinusoidally with respect to time and thus are indicative of the intensity pattern of the transmitted image along the scan row. After scanning a row, the CCD camera proceeds to scan the next row until all rows have been scanned and all pixels have been generated.

With the sinusoidally-varying medium described above, each row across the transmitted beam has an approximately-sinusoidal intensity variation. The frequency of the transmitted beam, in units of cycles per degree of the apparent field of view of the endoscope, is defined not only by the spatial frequency of the medium but also by the distance between the medium and the endoscope tip. As is described below, this distance is selected so that the frequency of the transmitted beam is approximately six cycles per degree of apparent field of view. In accordance with a further aspect of the invention, it has been determined that MTF measurements at a single spatial frequency of approximately six cycles per degree of apparent field of view are an accurate indication of optical instrument performance.

FIG. **22** is a schematic illustration provided for purposes of determining the frequency of the transmitted beam. The tip **418** of an exemplary endoscope **410** is spaced a predetermined distance "d" from a semi-transparent medium **416**. The exemplary endoscope **410** has an actual field of view of seventy degrees, which is thirty five degrees to each side **414**. The actual field of view is defined as the angular extent of an object visible through the endoscope subtended at the tip of the endoscope. Thus, the length "x" of the medium visible in each thirty five degree field of view is determined as follows:

$$x=(\tan 35°)(d)=(0.7)(d)\ \text{millimeters} \tag{1}$$

Accordingly, the length of the medium which lies in the entire seventy degree field of view is twice the length "x" as defined in equation (1):

$$2x=2(d)(\tan 35°)=(1.4)(d)\ \text{millimeters} \tag{2}$$

In the preferred embodiment, since the medium **416** defines a spatial frequency of approximately one cycle per millimeter, the number of cycles across the medium in this direction is determined approximately as follows:

$$\begin{aligned} \text{total cycles} &= (1\ \text{cycle/millimeter})\\ &\quad (2x\ \text{millimeters})\\ &= (1\ \text{cycle/millimeter})\\ &\quad ((1.4)(d)\ \text{millimeter})\\ &= (1.4)(d)\ \text{cycles in the}\\ &\quad \text{apparent field of view} \end{aligned} \tag{3}$$

As discussed above, in the preferred embodiment the desired frequency of the transmitted beam is six cycles per degree of apparent field of view. The exemplary endoscope **410** has an apparent field of view **412** of twelve degrees. The apparent field of view is the angle between the right and left sides of the image as subtended by the eye. The desired number of cycles across the medium in the apparent field of view is determined approximately as follows:

$$(6\ \text{cycles/degree})(12\ \text{degrees})=72\ \text{cycles in the apparent field of view} \tag{4}$$

Accordingly, the value of "d" is determined from the equality of relationships (3) and (4) for the desired number of cycles in the field of view:

$$(1.4)(d)=72 \tag{5}$$

$$\begin{aligned} d &= 72/1.4 \\ &= 51.4\ \text{millimeters} \\ &= 1.02\ \text{inches} \end{aligned} \tag{6}$$

Thus, the tip **418** of the endoscope **410** is spaced approximately two inches from the medium **416**. Since the distance d is known, the length of the medium which lies in the field of view is determined as follows:

$$\begin{aligned} 2x &= (1.4)(d) \\ &= (1.4)(2.02\ \text{inches}) \\ &= 2.83\ \text{inches} \end{aligned} \tag{7}$$

Conventional video systems scan at a rate of approximately one frame every $\frac{1}{30}$th of a second. Since each frame comprises a two-dimensional array which is 512 pixels×512

pixels, the video system **22** scans 512 rows every 1/30th of a second. Thus, the video system scans one row every 1/15360th of a second (one row every 65 microseconds). Since, from relationship (4) above, there are seventy two cycles in the field of view, the video system **22** scans 72 cycles in 65 microseconds if the horizontal scan direction is substantially parallel to the direction along the medium which varies at one cycle per millimeter.

The scan rate of 72 cycles in 65 microseconds defines a video frequency of the time-varying video signals which the video system generates:

$$72\ \text{cycle}/65\ \text{microseconds}=1.11\ \text{megahertz (MHz)}$$

Of course, the video frequency is easily determined for video systems which scan at a rate different than one frame every 1/30th of a second, and for video systems which scan at a number of cycles in the apparent field of view different than 72 cycles.

The time-varying video signals, like most signals, are at least partially corrupted by noise. In conventional video systems, the predominant form of noise is a color subcarrier signal having a frequency of approximately 3.57 MHz. The above-stated video frequency of 1.11 MHz is so close to the noise frequency of 3.57 MHz that a conventional low-pass filter, such as a Butterworth filter implemented in the frame grabber card, will not be able to substantially attenuate the noise signals without also attenuating the video signals. Thus, the filter will not be able to improve the signal-to-noise ratio.

Two quantities which determine the video frequency, the spatial frequency of the sinusoidally-varying medium **48** and the scan time of the video system **22**, cannot easily be adjusted. The spatial frequency of the sinusoidally-varying medium is selected for efficiently testing the endoscope, and the scan time of the video system cannot be changed without significant hardware redesign. Accordingly, the video frequency is preferably not adjusted by adjusting either of these two values. However, if the horizontal scan direction is transverse to the direction along the medium in which the intensity varies at one cycle per millimeter, then the video system scans less than 72 cycles in 65 microseconds. The number of cycles scanned in a row decreases as the scan direction becomes less parallel and more perpendicular to the direction of variance in the medium. As will be seen below, the frequency of the video signal will likewise decrease, further separating the video frequency from the noise frequency and thereby facilitating noise filtering.

FIGS. **23***a* and **23***b* illustrate the manner in which the total number of cycles scanned depends on both the horizontal scan direction and the direction along the medium which varies at one cycle per millimeter. FIG. **23***a* shows in schematic form an exemplary medium **420** in which the transmittance varies sinusoidally along a direction **430**. Maxima (or cycles) in the transmittance are indicated by reference numerals **421**, **422**, **424**, **426**, **428** and **429**. Thus, the medium **420** illustrated in FIG. **23***a* includes six cycles along the direction **430**. A horizontal scan direction **432** is substantially parallel to the direction **430** of the medium **420**. Accordingly, a scan across the scan direction **432** crosses six cycles from one end of the medium **420** to the other across a distance **434**.

FIG. **23***b* shows in schematic form another exemplary semi-transparent medium **440** which is substantially identical to the medium **420** of FIG. **23***a* but rotated with respect to the horizontal scan direction. The medium **440** defines a transmittance which varies sinusoidally along a direction **450**. Maxima (or minima) in the transmittance are indicated by reference numerals **441**, **442**, **444**, **446**, **448** and **449**. Thus, the medium **440** includes six cycles along the direction **450**. As shown, a horizontal scan direction **452** is transverse to the direction **450** of the medium **440**. Accordingly, a scan across the scan direction **452** crosses less than six cycles from one end of the medium **440** to the other across a distance **454** equal to the distance **434** in FIG. **23***a*.

Thus, decreasing the number of cycles scanned in a row by selecting a scan direction transverse to the direction of variance in the medium will likewise decrease the video frequency without changing the spatial frequency of the image. In fact, the angle between the scan direction and the direction of variance in the medium defines the decrease in the video frequency. The number of cycles scanned in a row is determined by the relationship:

$$\text{Cycles scanned}=(\text{Max Cycles})(\cos\theta)$$

wherein:

θ is the angle between the scan direction and the direction of variance in the medium; and

Max Cycles is the number of cycles scanned when $\theta=0$.

Similarly, the frequency of the video signal is determined by the relationship:

$$\text{Frequency}=(\text{Max Frequency})(\cos\theta)$$

wherein:

Max Frequency is the frequency when $\theta=0$.

Thus, to divide the video frequency of 1.11 MHz by a factor of three, the angle θ is selected in accordance with the following relationship:

$$\text{Frequency}=(\text{Max Frequency})(\cos\theta)$$

$$1.11/3=(1.11)(\cos\theta)$$

$$1/3=\cos\theta$$

$$\theta=71\ \text{degrees}$$

Thus, orienting the semi-transparent medium relative to the horizontal scan direction of the video system to form a 71 degree angle between the scan direction and the direction of variance in the medium reduces the video frequency approximately as follows: 1.11 MHz/3=0.37 MHz. This reduced video frequency is more easily distinguished from the noise frequency of 3.57 MHz by a low pass filter. For example, a fourth-order Butterworth filter having a "cut-off" frequency of 0.66 MHz substantially attenuates the 3.57 MHz noise signal while attenuating the 0.37 MHz video signal by less than 0.1 dB.

Of course, other values for the angle θ will reduce the video frequency by different amounts. For example, an angle of 40 degrees yields a decrease by a factor of 1.4, while an angle of 89 degrees yields a decrease by a factor of 57. Greater decrease factors may be produced by selecting angles which are even closer to 90 degrees, but selecting an angle of 90 degrees results in a frequency of zero.

As is known in the art, the fourth-order Butterworth filter has overshoot and ringing characteristics for step input signals. However, according to the "Handbook of Filter Synthesis" by Anatol Zverev, John Wiley and Sons, Inc., 1967, which is hereby expressly incorporated by reference as part of the present disclosure, the overshoot and ringing is reduced to about 1% after a delay of 10 normalized periods of the filter cut-off frequency. This delay is, in this

filter, only approximately 2.4 microseconds, which is less than 4.4% of the horizontal scan time and thus not a significant source of error.

FIG. 24 depicts an exemplary graph 460 illustrating in simplified form the attenuation characteristics of a low-pass filter. The graph 460 defines a first set of frequencies 462 which are virtually unattenuated, and a second set of frequencies 464 which are substantially completely attenuated. A frequency 470 is the video frequency, such as 1.11 MHz, when the horizontal scan direction is parallel to the direction of variance in the medium. A frequency 466 is the video frequency, such as 0.37 MHz, after selecting a horizontal scan direction transverse to the direction of variance in the medium. A frequency 468 defines a threshold below which the filter does not substantially attenuate signals. Another threshold frequency 472 defines the frequencies above which the filter substantially completely attenuates signals. Finally, a frequency 474 is the noise frequency, such as 3.57 MHz. The filter substantially attenuates the noise frequency 474 since it is greater than the frequency 472. In addition, the filter passes substantially unattenuated the frequency 466 since it is less than the frequency 468.

In response to a user command input through the GUI, the computer system 32 transmits any of the above-described displays to the printer 34. The printed display is useful in the analysis of test results, and thus in evaluating the performance characteristics of tested endoscopes, in that it may be transmitted (i.e., sent by mail, electronic mail or facsimile) to distant users unable to view, or otherwise access the monitor or computer system of FIG. 1.

In the preferred embodiment, the computer system 32 (FIG. 1) further comprises a database for storing, for each endoscope tested, a unique identifier for the endoscope, the endoscope manufacturer, diameter, length and tip angle, any reported and observed problems with the endoscope, the time and date of testing, the reason for testing, the test results, and the evaluation of the results. Such a database allows the system of the present invention to evaluate changes in endoscope performance after repair operations and over the lifetime of the endoscope. The database can be implemented with a variety of commercial software products, such as Microsoft Access™ or Claris FileMaker Pro™.

Although the invention has been shown and described with respect to a preferred embodiment thereof, it would be understood by those skilled in the art that other various changes, omissions and additions thereto may be made without departing from the spirit and scope of the invention as defined in the appended claims. For example, there are other fiber-optic scopes, known as bore scopes, which are similar to endoscopes for use in medical applications, but have much larger length-to-diameter ratios. Bore scopes are used to examine the internal subassemblies in large engines, compressors and turbine machinery. Such bore scope may be tested and evaluated using the system of the present invention with minimal modification of the preferred embodiment presented herein. Accordingly, this detailed description of a preferred embodiment is to be taken in an illustrative, as opposed to a limiting sense.

What is claimed is:

1. A method for evaluating the performance of an endoscope, comprising:

generating a beam of light defining a predetermined intensity pattern;

transmitting the beam through the endoscope;

generating signals indicative of the degree to which the endoscope attenuates the optical intensity of the transmitted beam at each of a plurality of predetermined locations within the beam.

2. The method of claim 1, wherein the step of generating the beam of light comprises:

transmitting a beam of light in a direction from a second end through a first end of the endoscope, and in turn onto a reflective surface.

3. The method of claim 2, wherein the step of transmitting the beam of light onto a reflective surface comprises:

transmitting a beam of light in a direction from the second end through the first end, and in turn onto a substantially nonspecular reflective surface defining an approximately uniform reflectance to thereby generate a nonspecular, reflected beam of approximately uniform intensity.

4. The method of claim 1, further comprising:

selecting the intensity of the generated beam such that the endoscope attenuates the intensity at locations in a central region of the transmitted beam to an intensity above a first predetermined intensity, and attenuates the intensity at locations at the periphery of the transmitted beam to approximately zero.

5. The method of claim 1, further comprising

selecting the intensity of the generated beam such that

(i) the endoscope attenuates the intensity at locations in a central region of the transmitted beam to an intensity above a first predetermined intensity;

(ii) the endoscope attenuates the intensity at locations between the center and the periphery of the transmitted beam to an intensity between the first predetermined intensity and a second predetermined intensity lower than the first predetermined intensity; and

(iii) the endoscope attenuates the intensity at locations at approximately the periphery of the transmitted beam to approximately zero.

6. The method of claim 1, further comprising:

generating for each of a plurality of locations in the transmitted beam signals indicative of one of a plurality of intensity ranges including the intensity of the respective location.

7. The method of claim 2, wherein the step of transmitting the beam of light onto a reflective surface comprises:

transmitting a beam of light in a direction from the second end through the first end, and in turn onto a mirror-like surface defining an approximately uniform reflectance to thereby generate a specular, reflected beam.

8. The method of claim 1, further comprising:

selecting the intensity of the generated beam such that

(i) the endoscope attenuates the intensity above a first predetermined intensity at locations in the transmitted beam corresponding to working fibers, and

(ii) the endoscope attenuates the intensity to a second predetermined intensity less than the first predetermined intensity at locations in the transmitted beam corresponding to damaged fibers.

9. The method of claim 8, wherein the generated beam is selected such that the endoscope attenuates the beam to approximately zero intensity at locations corresponding to damaged fibers.

10. The method of claim 1, wherein the step of generating the beam comprises:

filtering a beam through a semi-transparent medium having a transmittance which varies periodically along at least one predetermined direction within the medium, thereby defining a generated beam having an intensity which varies periodically along the at least one predetermined direction;

and further comprising the step of generating signals indicative of the modulation at a location in the beam transmitted through the endoscope based on the signals indicative of the degree to which the endoscope attenuates the intensities at predetermined locations.

11. The method of claim 10, wherein the step of filtering the beam comprises:

filtering the beam through a semi-transparent medium having a transmittance which varies approximately sinusoidally along the medium in a first direction, and which is substantially constant along a second direction transverse to the first direction, thereby defining a generated beam having an intensity which varies approximately sinusoidally in the first direction.

12. The method of claim 10, further comprising:

generating signals indicative of the intensity at a plurality of approximately collinear locations in the transmitted beam.

13. An apparatus for evaluating the performance of an endoscope, comprising:

means for generating a beam of light defining a predetermined intensity pattern and for transmitting the beam through the endoscope; and

means for generating signals indicative of the degree to which the endoscope attenuates the optical intensity of the transmitted beam at each of a plurality of predetermined locations within the beam.

14. The apparatus of claim 13, wherein the means for generating the beam of light comprises a reflective surface defining a substantially uniform reflectance.

15. The apparatus of claim 13, wherein the means for generating the beam of light comprises a nonspecular reflective surface.

16. The apparatus of claim 14, wherein the means for generating the beam of light comprises a mirror-like surface.

17. The apparatus of claim 13, wherein the means for generating the beam of light comprises a semi-transparent medium having a transmittance which varies periodically along the medium.

18. An apparatus for evaluating the performance of an endoscope, comprising:

a nonspecular reflective surface;

a mirror-like surface;

a semi-transparent medium having a transmittance which varies periodically along the medium;

a light source connectable between (i) a first position in which the light source transmits light through the endoscope from a second end through a first end of the endoscope and onto one of the nonspecular reflective surface and the mirror-like surface, and in turn back through the endoscope, and (ii) a second position in which the light source transmits light through the semi-transparent medium into the first end and through the second end of the endoscope; and

means for generating a first set of signals indicative of the optical intensity of the beam at each of a plurality of predetermined locations within the beam after transmission of the beam through the endoscope in the direction from the first end toward the second end of the endoscope.

19. The apparatus of claim 18, further comprising:

means for generating a second set of signals responsive to the first set of signals which are indicative of at least one performance characteristic of the endoscope.

20. A method as defined in claim 1, wherein the step of generating signals includes generating signals indicative of the degree to which the endoscope geometrically distorts an image of the transmitted beam at different locations within the beam.

21. A method as defined in claim 1, wherein the step of generating signals includes generating signals indicative of the degree to which the intensity of the beam is non-symmetrical about an axis of the beam.

22. A method as defined in claim 21, wherein the generated signals are indicative of the degree to which an image of the transmitted beam is non-symmetrical about an axis of the beam.

23. A method as defined in claim 1, wherein the step of generating signals includes generating an image of the transmitted beam on a display, and generating signals indicative of the intensity of a plurality of pixels defining the image on the display, wherein the intensity of each pixel is indicative of the intensity of the transmitted beam at a corresponding location within the beam.

24. A method as defined in claim 1, wherein the step of generating signals includes generating signals indicative of whether the attenuation of the transmitted beam at a predetermined number of locations within the beam is less than a predetermined attenuation.

25. A method as defined in claim 1, wherein the endoscope includes a plurality of optical fibers, and the step of generating signals includes generating signals indicative of at least one of (i) the location of any damaged optical fibers, and (ii) the number of working optical fibers.

26. A method as defined in claim 1, wherein the step of generating signals includes generating signals indicative of the degree to which the endoscope reduces the contrast of an image of the transmitted beam.

27. A method as defined in claim 26, wherein the step of generating signals further includes generating signals indicative of the degree to which the endoscope reduces the modulation of an image of the transmitted beam at predetermined locations within the beam.

28. A method as defined in claim 1, wherein the endoscope includes a lens and a plurality of optical fibers, and the step of generating signals includes generating signals indicative of at least one performance characteristic of each of the lens and optical fibers.

29. A method as defined in claim 1, wherein the step of generating signals includes generating signals indicative of the degree to which the endoscope transmits light below a predetermined intensity level.

30. An apparatus as defined in claim 15, further comprising a substantially transparent film defining thereon a reference pattern overlying the nonspecular reflective surface.

31. An apparatus as defined in claim 30, wherein the reference pattern defines a plurality of reference points, and each reference point is spaced a predetermined distance relative to an adjacent reference point.

32. An apparatus as defined in claim 16, wherein the mirror-like surface defines a reflectance within the range of approximately 5% to approximately 40% reflectance.

33. An apparatus as defined in claim 14, further comprising means for adjusting the distance between the reflective surface and a tip of the endoscope.

34. An apparatus as defined in claim 13, wherein the means for generating signals includes a video system generating signals indicative of an image of the transmitted beam.

35. An apparatus as defined in claim 34, further comprising a display coupled to the video system for displaying an image of the transmitted beam.

36. An apparatus as defined in claim 34, wherein the video system includes a video camera for recording images of the

transmitted beam, and a signal processor for generating signals indicative of the recorded image.

37. An apparatus for evaluating the performance of an endoscope, comprising:

a light source connectable to the endoscope for transmitting a beam of light through the endoscope;

at least one target optically coupled to the transmitted beam and forming a predetermined intensity pattern within the beam; and

at least one sensor coupled to the endoscope for receiving the transmitted beam defining the predetermined intensity pattern, and generating signals indicative of the degree to which the endoscope attenuates the optical intensity of the beam at each of a plurality of predetermined locations within the beam.

38. An apparatus as defined in claim 37, wherein the at least one target is defined by at least one of:

(i) a reflective surface optically coupled to the transmitted beam by mounting the reflective surface adjacent to the endoscope for reflecting the transmitted beam through the endoscope, and

(ii) a semi-transparent medium optically coupled to the transmitted beam by mounting the semi-transparent medium adjacent to the endoscope for filtering the beam prior to transmission through the endoscope.

39. An apparatus as defined in claim 38, wherein the reflective surface defines a substantially uniform reflectance.

40. An apparatus as defined in claim 38, wherein the reflective surface defines a nonspecular reflective surface.

41. An apparatus as defined in claim 38, wherein the semi-transparent medium defines a transmittance which varies periodically along the medium.

42. An apparatus as defined in claim 38, wherein:

the light source is connectable between (i) a first position in which the light source transmits light through the endoscope from a second end through a first end of the endoscope and onto the reflective surface, and in turn back through the endoscope, and (ii) a second position in which the light source transmits light through the semi-transparent medium into the first end and through the second end of the endoscope; and

the at least one sensor generates signals indicative of the optical intensity of the beam at each of a plurality of predetermined locations within the beam after transmission of the beam through the endoscope in the direction from the first end toward the second end of the endoscope.

43. An apparatus as defined in claim 37, wherein the at least one sensor includes a video camera for recording images of the transmitted beam, and a signal processor for generating signals indicative of the recorded image.

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UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 5,953,112

DATED : September 14, 1999

INVENTOR(S) : Eric Rosow, Finton Beatrice, Joseph Adam and Curtis Youngdahl

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 17, line 67, after "three-dimensional" insert --(not shown)--.

Signed and Sealed this

Second Day of May, 2000

Attest:

Q. TODD DICKINSON

Attesting Officer

Director of Patents and Trademarks